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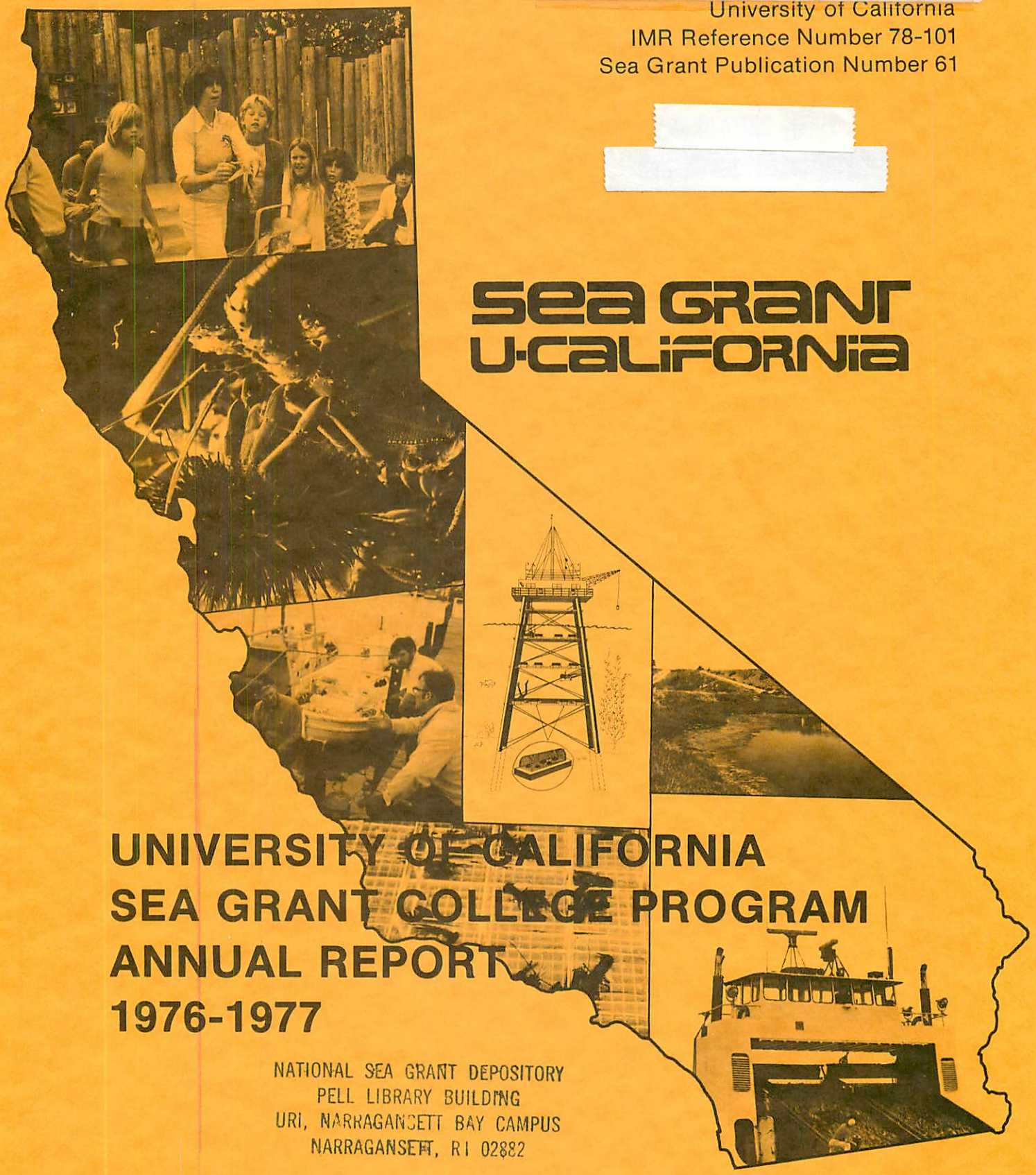

sea grant
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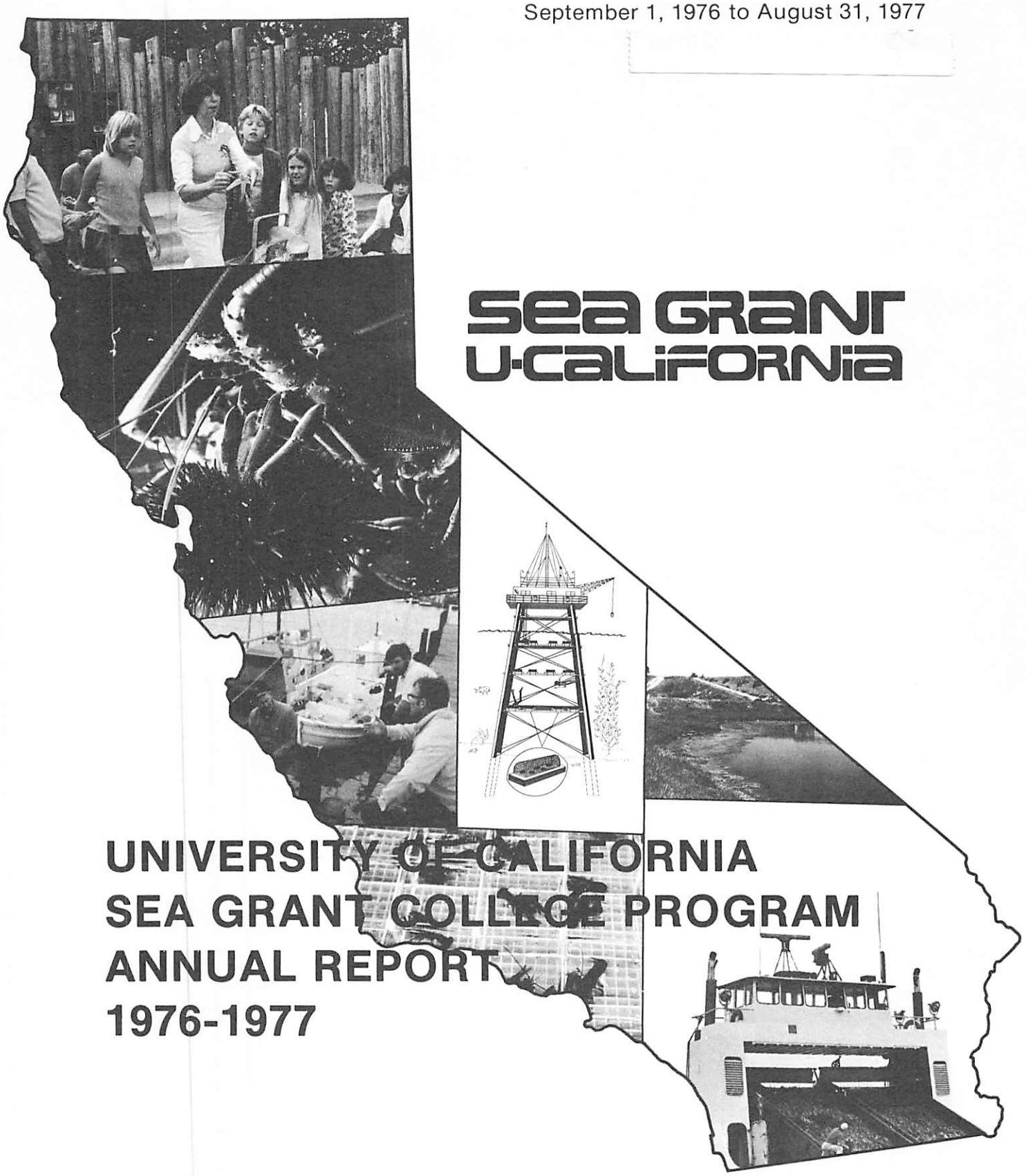
UNIVERSITY OF CALIFORNIA SEA GRANT COLLEGE PROGRAM ANNUAL REPORT 1976-1977

A report on the University of California Sea Grant College Program for September 1, 1976 to August 31, 1977

September 1, 1976 to August 31, 1977



SEA GRANT
U-CALIFORNIA

UNIVERSITY OF CALIFORNIA
SEA GRANT COLLEGE PROGRAM
ANNUAL REPORT
1976-1977

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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."

In practice 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.

In California strong cooperative links have been forged among government, industry, universities, colleges, and the public which provide the critical interaction among members of these sectors of society to develop a better understanding of what the real problems are. To solve these problems research projects have been established that emphasize: coastal resources, marine aquaculture, fisheries; energy and new products from marine sources. Practical ocean and coastal research experience is provided to about 70 graduate students in association with Sea Grant research projects each year. Information is disseminated through publications in journals and reports, and through the marine and coastal advisory services provided statewide by the UC Cooperative Extension offices located in each county and the participating campuses to ensure implementation of research results.

The California Sea Grant College Program is administered by the statewide University of California Institute of Marine Resources. The policy of the Program is to seek out the most qualified research talent and best application-oriented research projects wherever they may exist in the state's institutions of higher education. Currently projects are under way at seven University of California campuses (Berkeley, Davis, Los Angeles, Riverside, San Diego, Santa Barbara, and Santa Cruz), Humboldt State University, San Diego State University, the Moss Landing Marine Laboratories (a consortium of six state universities and colleges — Sacramento, San Francisco, San Jose, Stanislaus, Hayward, and Fresno), California Institute of Technology, Stanford and the University of San Diego. The philosophy of the program is to seek solutions to identified important local needs yet to encourage attainment of a fundamental understanding that can be applied to that class of problems wherever they may occur nationally or internationally.

In summary, Sea Grant is a pioneering effort involving state, regional, and local interests directly in the formulation of federal research and development priorities and the conduct of the resulting programs. The strong partnership developed among the state's universities, industry, the state of California, and the federal government, each of whom directly funds the program, is working. Our experience can be a model for national and international endeavors to tap the intellectual potential and developmental expertise residing in industry, Academia and Government to meet contemporary ocean and coastal needs.

James J. Sullivan
Program Manager

EDUCATION

A major part of Sea Grant's effort lies in the realm of education, to broadcast research findings in the most effective way, and to expedite and facilitate the application of this new knowledge by user groups. Another aspect is Sea Grant's involvement in the training of professional marine scientists. Under its partial sponsorship, the Applied Ocean Science Curriculum from 1968 through 1977 has had a total enrollment of 272 graduate students. A total of 40 advanced degrees have been awarded: 24 M.S.'s and 16 Ph.D.'s. The experimental undergraduate technician training program conducted by San Diego State University and Scripps Institution of Oceanography was concluded in 1975. During its several years of operation, 36 students received training in the program. Of these, 12 are currently employed in technical or professional marine or related occupations, 16 are continuing their educations, and two are employed elsewhere.

Sea Grant Trainees

James J. Sullivan

Graduate students are an integral part of most Sea Grant projects and a vital part of the UC Sea Grant College program. Meaningful completion of the projects with which they are associated can be used in partial satisfaction of their degree requirements. Accounts of independent research accomplished by these students during the 1976-77 grant year are reported under the titles of the research projects with which they were associated. Their complete reports are available from the Sea Grant Publications office (see note on inside back cover of this report).

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

Thesis project

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

In 1976-77, there were 64 Sea Grant Trainees assigned to 36 projects on six UC and two State University campuses and at one Private School, funded by the UC program. They functioned in virtually all areas of marine related research.

MARINE ADVISORY SERVICES

The statewide Sea Grant Marine Advisory Program, which is part of the UC Cooperative Extension system, underwent a major expansion in 1975-76. Two area Marine Advisors were added – one serving the counties of Ventura, Santa Barbara, and San Luis Obispo, the other in Monterey and Santa Cruz counties – to complement the two who have been serving the San Diego and Marin-Mendocino coastal areas. Recruitment for a third position in San Francisco and San Mateo counties was completed and that Advisor is now on the job. This expansion is in line with the planned growth of the advisory program and reflects the needs identified in the California Marine Advisory Service Plan currently under revision. Coordination of all Sea Grant Marine Advisory Programs in the state has been improved by involving representatives of the U.S.C. and H.S.U. Marine Advisory services in the work of the UC advisory program planning committee. The Aquarium-Museum at the Scripps Institution of Oceanography was visited by about 60,000 students in organized school groups, and members of its staff continued to present the latest information on marine ecology, emphasizing such Sea Grant objectives as conservation and wise utilization of marine resources.

Marine Advisory Programs

Maynard W. Cummings

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

Introduction

The UC Marine Advisory Program structure is a component of the University's Cooperative Extension system, which has statewide staffing in every county and which reaches into campus departments for research and subject matter back-up. Marine Advisors are assigned with other county extension staff, each with an area responsibility for overall Sea Grant educational activities and emphasizing information applicable to local needs and problems. They are given in-depth subject matter support and program assistance by campus-based Specialists with statewide assignments.

The advisory program goal is to make the best information and technology available to all California citizens who have need of it in working with the State's ocean and coastal resources. The size and diversity of this coastal region, the variety of resources and the intensive demands upon them call for maximum effort by the advisory program staff in approaching this goal.

Each year has seen progress in reaching the heterogeneous audiences of Sea Grant. There is steady growth in staff numbers and a great increase in total program capability and information delivery through experience and coordination of available human resources.

Changes to the UC Marine Advisory Service staff during the year

A most grievous loss was the death of Monterey Bay Area Advisor, Dr. Thomas W. Thompson. "Tommy", as he was known to everyone, suffered a fatal heart attack in February, 1977, after only one year as Advisor for Santa Cruz and Monterey Counties. However, he had previously been in charge of advisory programs as well as the squid research project at Moss Landing Marine Laboratories, had wide experience elsewhere, and was such a talented and dynamic person that his program had from the beginning been a model of diversified excellence. He left more to be filled on the job than large shoes, however, because his program was well established. His involvement with the mariculture industry led to the formation of the California Aquaculture Association which continues as a growing industry organization. Dr. Thompson also had developed an agreement with the City of Salinas for use of some waste water pond facilities for aquaculture projects. He had put together a citizens non-profit aquaculture research group, which, with marine advisory staff leadership, Sea Grant and other university research support, and industry cooperation, is a continuing organization. A principal collaborator is Dr. G. Gall, UC-Davis animal scientist, whose trout genetics work is supported by the California Department of Fish and Game. Some of these trout were used in the Salinas studies last year.

New Appointments. By the close of the fiscal year, Mr. James B. Waldvogel had been selected to fill the Monterey Bay position vacancy.

A San Francisco-San Mateo Area Marine Advisor was added, in the person of Mr. Andrew T. Manus. This appointment not only makes full-time advisory service available in that area but also relieves the Advisors on either side and the statewide Specialists. Additionally, the San Francisco-based Advisor is particularly knowledgeable in coastal resources management and marine recreation planning, which can assist Advisors in other areas who do not have this special knowledge.

Difficulty has been experienced in recruiting for a Marine Advisor authorized last year for Los Angeles and Orange Counties. There were few qualified candidates and, unfortunately, the top three who showed promise all accepted other employment before the job

offer could be made. Recruitment has been restarted. The University of Southern California Sea Grant advisory program has offered office space for this position. This arrangement should facilitate even closer coordination between our two institutional programs. There was considerable interaction last year with USC Specialists conducting work jointly with UC Marine Advisors and Specialists. USC staff also were invited to participate in UC advisory staff meetings.

A recruitment which was successful, although selection was difficult for the opposite reason, there being several highly qualified candidates, was that to fill a new, statewide Aquaculture Specialist position. Cooperative Extension is sharing support for this position with Sea Grant. The new Specialist, Dr. Fred S. Conte, is located at the Davis campus Sea Grant advisory unit, as of November 1, 1977. This assignment will be a very valuable one, both as an information source to the advisory staff and to industry and as a research collaborator.

The Santa Barbara Area Marine Advisor, Mr. John B. Richards, was appointed to the project advisory committee dealing with the new Sea Grant research project on abalone restoration and management. He will be particularly involved with industry liaison, abalone habitat survey locations and quantification sampling after planting.

Intercampus cooperation and research integration

A significant advance in the concept of sharing expertise was the decision last year by Humboldt State University to enter the UC Sea Grant College Program. For the two Marine Advisory Programs, it was a valuable opportunity for integration.

There was increased interaction with researchers by advisory program staff. The Santa Barbara Area Marine Advisor, Mr. Richards, worked with Sea Grant and the Department of Fish and Game research staff, as well as with UC-Santa Barbara professors and the abalone divers and processors, in helping initiate a new major Sea Grant Research project on abalone restoration and management.

The Marin-Sonoma-Mendocino Area Advisor, Bruce Wyatt, contacted UC-San Diego scallop researchers and transferred some cultural technology to local industry in his area interested in establishing scallop grow-out facilities. He also worked with Dr. Howard A. Bern, the UC-Berkeley researcher on salmon endocrinology involved in silver salmon smoltification research.

Salmon-rearing projects

Mr. Wyatt last year increased his salmon-rearing project activities. During July he supervised delivery of over 1/4 million small salmon at several rearing sites in the three counties and will continue with these projects and others involving steelhead until the fish are released. These salmon-steelhead rearing projects face not only adversities such as drought (at the freshwater holding tanks) and disease, but also such unexpected calamities as a forest fire which burned a water pipe cutting off the supply and at another location wild pigs rooting up and destroying the pipeline.

The San Diego Marine Advisor, Mr. Arthur O. Flechsig, is coordinating a new salmon-rearing project with Sea Grant aquaculture researchers at San Diego State University and San Diego Sea World. These salmon, new to San Diego Bay, will be made available by the California Department of Fish and Game early next fiscal year.

Fish waste processing

The Sonoma-based Marine Advisor, Mr. Wyatt, and the statewide Specialist in seafood technology, Dr. Robert J. Price, worked with a Fort Bragg fisheries plant on utilization of fish waste. They conducted experiments at the UC-Davis campus Food Science and Technology Department fish processing pilot plant, converting fish waste into a liquid form for use as fertilizer, animal feed additive or other possible uses.

Dr. Price, with Humboldt State Marine Advisors, met with a Crescent City firm to discuss and recommend fish processing waste utilization. They also met with representatives of this and other companies, regulatory agencies and city government to discuss a consulting firm's recommendations for waste water management. Two large fish processing companies in Eureka are considering setting up their own waste water pretreatment plants. The Advisors and Specialist are consulting regularly with industry and local government as an advisory program activity.

Satellite imagery program

The satellite imagery program application to help fishermen in fish location and conservation is continuing. All Advisors and the Marine Resources Specialist, Mr. Christopher M. Dewees, participated in the project, which is being used by fishermen regularly. Cooperative work with the National Environmental Satellite Service (NESS), the National Weather Service (NWS), the National Aeronautics and Space Administration (NASA) and the National Marine Fisheries Service (NMFS) was aimed at making the program as reliable and useful as possible.

Work continued on developing methods to get the satellite imagery charts to fishermen on a timely basis, especially when the fishermen are at sea. Development of a timely, reliable delivery system is the key to the continued success of the program. The MAP staff and other agencies also worked on the collection of ground truth data to supplement and confirm the information supplied by the satellite images. Work in these areas will continue.

Two problems were identified that need to be investigated. One is how best to measure ocean surface activity during periods of cloud cover. The second is to develop the capability to predict the formation and movement of ocean temperature fronts, especially when satellite images are not available.

Charts from satellite images are being distributed to fishermen by radio facsimile and through the Area Marine Advisors. The goal of the MAP staff is to develop the satellite imagery program to a point where it can be taken over by the National Weather Service on a continuing routine basis.

Other activities

Dr. Price, the Seafood Technology Specialist, and Mr. Richards, the Santa Barbara Advisor, have been working with a Cal Poly, San Luis Obispo, food scientist on minced fish products obtained from northern California (Eureka) fish. This Specialist also is collaborating with UC-Davis food scientists and agricultural engineers on experimental machine shrimp peeling and squid processing, and they are particularly studying ways of recycling water used in shrimp peelers.

Dr. Price has been actively working with the State Department of Health in an attempt to establish new regulations to permit bay mussel harvesting and aquaculture in suitable areas, particularly Tomales Bay. The Department of Health established a Shellfish Quarantine Committee, on which he serves, to further study the problem. He also has responsibility for setting up meetings and organizing technical agendas for the regular meeting of the California Seafood Institute.

Messrs. Flechsig and Richards, and Mr. Dewees alternated on various legs of a National Marine Fisheries Service research cruise. Representative commercial fishermen also participated in testing fishing and locating possible new fishing grounds on this exploratory fishing cruise of FRS-44, the *David Starr Jordan*. The cruise was organized by NMFS Tiburon Laboratory staff, with whom the advisory staff regularly work on applied fishery research problems.

Marine educational and publications programs

Mr. Dewees spent considerable time promoting marine education programs. He served on a Sea Grant committee by that name which prepared a proposal for special funding for a three-year marine education program. Teaching materials would be developed and evaluated, and teacher training workshops established; unification of the California marine education effort is needed. His marine education activity in fish printing has resulted in a new national organization, the Nature Printing Society.

At Eureka, the Marine Advisors plan to develop marine education materials and to present regular lectures in lower grade level classrooms. A county-paid Comprehensive Employment and Training Act employee was obtained to assist in this program in Eureka. HSU Advisors prepared a State Park Nature Trail brochure.

A Sacramento County UC Farm Advisor has worked with the Marine Advisory staff in developing marine education materials for classroom use and in 4-H Club programs. Sacramento County has 35 members in 4-H Marine Science Clubs and 86 in 4-H marine school programs. Statewide, there are almost 1000 members in Marine Science 4-H Clubs.

A slide-tape cassette set, "Introduction to intertidal plants and animals", was developed for use by schools, 4-H youth, and Scripps training audiences. Another slide set on "Hypothermia", based on a British Columbia publication "Man in cold water", was

completed. It will be shown for the first time at the Pacific Fish Expo in Seattle. A number of new publications were authored by advisory staff and several publications were reprinted during the year. A very important reference book, "Guide to the coastal marine fishes of California", California Fish Bulletin No. 157, was printed by the UC Division of Agricultural Sciences in cooperation with the California Department of Fish and Game and the UC Extension Wildlife and Sea Grant Program. This book, out of print for several years, is a valuable teaching and standard reference and identification text for West Coast fishes. The new version carries both the Department of Fish and Game and Sea Grant Marine Advisory logos.

The *Marine Advisory Newsletter*, published monthly, has a mailing list of over 4000. Most Advisors also have their own local newsletter.

The extended jurisdiction legislation has created not only fishery management changes and regulatory bodies, but also program demands upon Marine Advisors. Fishery Management Council meetings are attended by the Advisor in whose area each meeting is held, and sometimes by other staff as well, and a summary is prepared for information of other Advisors. Council information is distributed and interpreted for fishermen and other audiences as appropriate. Information is exchanged with Sea Grant staff in other Pacific states regarding actions and management plans of the several councils involved with Pacific fisheries.

The Marine Advisory Program office at UC-Davis, in addition to handling advisory publications, is the library and distribution center for all UC Sea Grant publications. Thousands of these annually are mailed in response to direct request, distributed by Marine Advisors and other University offices, or picked up in person by people needing information.

Assistance in coastal resources management to local planning agencies and government was greatly accelerated in the past six months, largely by the presence of the San Francisco-San Mateo Marine Advisor, Mr. Manus. A Coastal Issues Workshop was held in conjunction with the San Mateo County Planning Department, the first of several public meetings in that county with reference to requirements of the Coastal Act. Several marina and park sites were visited with site planning teams from county and state agencies to make potential use recommendations. The Cooperative Extension - Marine Advisory mix of local University staff is able to gain access to landowners' thinking as well as to their properties to assist in planning for recreational area selection. The State Department of Recreation is moving prudently in land acquisition matters and seeking capable counsel such as that provided by the Cooperative Extension and Sea Grant advisory program staff. Continuing assistance is being given to the San Mateo Harbor District and other agencies and individuals involved with the Pillar Point Harbor development plans.

The San Francisco-San Mateo Advisor, Mr. Manus, participated as an instructor in coastal resources management at a five-day Marine Science Workshop for teachers and youth leaders offered by the private Marine Ecological Institute of Redwood City. He also participated in a planning workshop called by the UC Sea Grant College Program Manager for considering the functions and operation of a proposed Regional Coastal Information Center for California.

UC Marine Advisory Staff Meetings; Presentations; and Workshops

Two statewide staff meetings were held during the year, one in Santa Barbara and the other at Bodega Bay.

The Seafood Technology Specialist, Dr. Robert J. Price, gave a presentation on television about some underutilized seafood specialties. The Advisory Program Coordinator, Mr. Maynard W. Cummings, and Marine Resources Specialist, Mr. Christopher M. Dewees, also appeared on the show in an interview with the program announcer, which gave them an opportunity to describe Sea Grant Advisory Programs to a Sunday prime-time viewing audience.

Highlights for the year in seafood technology were a marketing management workshop for seafood industry professionals organized jointly with Oregon State University Sea Grant staff, and the long-running series of consumer seafood education workshops. The latter are held by local Marine Advisors and Cooperative Extension Home Advisors and Consumer Science Specialists. All of the Marine Advisor areas held one or more of these very popular workshops which draw audiences in the hundreds wherever they are held. There were five in the Santa Barbara area alone where both the Marine Advisor and Home Advisor have very active consumer education programs. They, with 4-H youth club members, served seafood specialty samples

to more than 1800 people at the annual Santa Barbara fishermen's festival.

There were many other workshops held by the Marine Advisors:

- Fisheries oceanography at Monterey, San Luis Obispo, Moss Landing, Santa Cruz, Bodega Bay, Fort Bragg
- Sharks and shark fishing at Watsonville, Santa Barbara, San Luis Obispo
- Vessel sounds and bonding at Watsonville
- Business management at San Diego, Morro Bay, and Santa Barbara
- Limited entry at San Diego
- Ports and harbors at Watsonville
- Fishing vessels safety at Eureka

Publications

California Fish Bulletin No. 157: Guide to the coastal marine fishes of California. Reprint, California Department of Fish and Game.

Marine Brief No. 2: Paralytic shellfish poisoning and red tides.

Idem, No. 3: Catching, cleaning, cooking squid.

Idem, No. 4: Preparation of shark and skate.

Marine Advisory Publication Leaflet No. 2550: Identifying seashore birds.

Idem, No. 2911: Sharks — An annotated list of selected references.

Idem, No. 2939: Upwelling in California coastal waters.

Idem, No. 4-H 242: Developing local 4-H marine science programs.

Idem, No. 4-H 246: Using drift bottles to measure ocean currents.

Ventura County Marine Advisory Publication: Marine education activities for youth.

Cooperating Organizations

California Department of Fish and Game

Counties of Del Norte, Humboldt, Mendocino, Sonoma, Marin, San Francisco, San Mateo, Santa Cruz, Monterey, San Luis Obispo, Santa Barbara, Ventura, Los Angeles, Orange, San Diego

Humboldt State University, Arcata, California

Moss Landing Marine Laboratories, Moss Landing, California

National Environmental Data Service, Redwood City, California

National Marine Fisheries Service, La Jolla, Terminal Island and Tiburon, California

National Weather Service, Redwood City, California

Pacific Area Sea Grant Advisory Program

San Diego State University, San Diego, California

University of California —
Berkeley, Davis, Los Angeles, Santa Barbara, Santa Cruz, IMR, SIO, Bodega Marine Laboratory, Cooperative Extension, and the Division of Agricultural Sciences

University of Southern California, Los Angeles, California

Publications and Public Advisory Services

San Diego
A/P-1

Jeffery Frautschy

The oceans are a major factor in understanding man's role, position, and accommodation on this planet, and in comprehending the impact of his rapid emergence as a geochemical, geophysical and biological force. Thus, 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 1975-76 Annual Report, the 1976-77 and 1977-78 Program Directories, and the 1977-78 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.

Ocean Education for the Public

Donald W. Wilkie, David Coon, and William T. Doyle

The primary objective of the Aquarium-Museum at Scripps is to increase public understanding of the marine sciences through education programs and exhibits. An expanding education effort offers programs including structured field trips for over 61,000 students annually, teacher workshops, and advisory assistance to school districts. The Marine Science Institute at Santa Barbara has continued its educational role in the community by organizing marine laboratory tours and by improving its displays. The purpose of the Ocean Education Program at Santa Cruz is to provide the public with first-hand information on the identification and natural history of marine organisms in the intertidal and coastal environments through a direct, guided field experience. In addition, the field trip and supplemental slide show and curricular materials offer information on the management and conservation of marine resources.

The worldwide reputation of Scripps Institution of Oceanography enables the Aquarium-Museum to present an invaluable marine education to the public. Exhibits are designed around the research programs at Scripps to help the general public become informed and effective voters. Education programs and materials are provided for teachers, schools, and school districts, so that marine science can be incorporated into curriculum areas such as sociology. Sea Grant goals of wise use of marine resources are at the heart of the message of our far-reaching, expanding education program. This requires a professional staff and sufficient funds to develop and distribute education materials and plan exhibits.

In addition to the development of marine education programs, the Aquarium-Museum responds to the multitude of requests as a resource center for ocean information. Concerned citizens, classroom teachers, educators designing new courses, career counselors, park and recreation personnel, scientists, and other museum, zoos, and aquaria request technical advice which the education department of the Aquarium-Museum strives to fulfill.

Education program

During the 1976-77 school year, 61,650 students participated in the education program at the Aquarium-Museum. This program, which is conducted by trained volunteer teachers (docents), is designed to incorporate marine education into the general curriculum so that future leaders may be well informed voters. Education materials, which are mailed to each teacher, include pre-visit and post-visit questions and answers to be used in the classroom, and a guidesheet with questions to be answered at the Aquarium from the students' observations. This format, which was originated at the Aquarium-Museum 10 years ago, has proven so effective that it has been duplicated by other museums, zoos, and aquaria.

Outreach program

Busing problems continue to prevent many schools from participating in field trips. "Outreach" docents travel to these schools, bringing with them marine specimens and giving slide-illustrated lectures. Forty schools and

almost 2000 students partook in this extension of the education program. In addition, learning centers are set up in the school library for teachers to organize their own mini-marine biology courses. City libraries in Del Mar and Chula Vista have requested our materials and docents, and the Rancho Santa Fe library rewarded students who read over 50 books with a special field trip to the Aquarium.

Career experience program

Highly motivated high school students who plan a career in marine biology or aquariology are given an in-depth course, including laboratory and field work as well as classroom instruction. These students often return to the Aquarium in the summer through college and graduate school for further study.

Intern trainee apprenticeship program

College and high school students are trained in the practical aspects of aquarium management, such as water quality, feeding techniques, disease treatments, and collection of specimens. We are participating in the federal job training program by training Comprehensive Employment Training Act employees in laboratory, aquariology and secretarial positions.

Summer courses and winter workshops

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

In-service training for teachers

"Behavior and ecology of fishes from California and the Gulf of California" was the seventh symposium given annually for teachers to make available current, scientific marine information for their use in the classroom. Many teachers travel from all over California and Arizona to attend these symposiums.

Docent training program

Interested volunteers from the community are trained to help with the school students in a lecture and laboratory program each fall. Monthly lectures and field trips are held subsequently, with additional information from fact sheets, an active library, and tapes.

San Diego-La Jolla underwater park guides

The Aquarium staff trains and organizes a special group of docents who act as underwater park guides to promote conservation. During the daytime low tide series, these docents patrol the tidepool areas wearing Scripps jackets to encourage conservation measures and answer questions.

School districts advisory services

Encouraging school districts to include more marine education is a primary goal of the Aquarium staff. Two school districts used grants for innovative education to support mini-marine biology courses designed by the education department of the Aquarium. Cardiff and Chula Vista provided the classrooms, paid our docent teacher, and utilized our books, slides, films, and education materials. We are pleased that the San Diego City schools have requested us to offer classes in their Mentally Gifted Minor program for the next year.

Spanish language program

Many California school children are from Spanish-speaking homes, so the education program has been translated into Spanish, and Spanish-speaking docents are available. We also participate in "Project Amigos", a program sponsored by the City of San Diego for science winners from all the states of Mexico, when they make their annual field trip to the Aquarium.

The university People-to-People organization helps sponsor the library at the Ensenada, Mexico, oceanographic college, Escuela Superior de Ciencias Marinas. Aquarium docents act as guides and interpreters when the students and faculty visit the Scripps Institution laboratories and the Aquarium-Museum in La Jolla.

Junior Oceanographers Corps (J.O.C.)

J.O.C. completed its 22nd year as a lecture and field trip club for young marine enthusiasts from the fourth grade through high school. Many of the Corps' members enter the career experience and intern trainee programs.

Senior Oceanographers Corps (S.O.C.)

Many senior citizen clubs request various programs which we tailor to their individual needs. Sun City and Leisure World visit annually; The Institute for Continued Learning is on our UC campus, and we provide field trips, films, and lectures.

Advisory services

Many people consult Scripps for current scientific information on marine matters, and the Aquarium staff responds to many of these inquiries.

Teachers, schools, and school districts ask for education materials, books, slides, films, and help in designing courses. Other Sea Grant programs, such as that of the University of New Hampshire, request assistance in setting up their marine education programs, as did the North Carolina Marine Science Center. We are cooperating with UC-Davis in enlarging the 4H participation in marine areas.

Other museums, zoos, and aquaria frequently request advice on both education programs and technical matters such as designing seawater systems, disease treatments, nutrition, and collecting techniques.

The SIO Aquarium-Museum is closely linked with the MSI Community Education Program at UC-Santa Barbara and the Ocean Education Program at UC-Santa Cruz. Presently, a proposal is being drafted to establish a statewide marine education project.

MSI COMMUNITY EDUCATION PROGRAM AT UC-SANTA BARBARA

During the past year, almost 3,000 people have been able to see, touch, and carefully examine ordinarily inaccessible marine plants and animals that are typical of the waters of the Santa Barbara Channel. With the help of graduate and undergraduate students, special diving and net collections have been made, displays created, and instructional tours given in the marine laboratory at UC-Santa Barbara. These tours and displays are open to any interested community groups, three times per year, at the end of each academic quarter. During this time, four consecutive days are devoted to community as well as student education. This has proven to be a popular and successful means of making marine science

activities known to the community, and stimulating interest in these activities.

This year improvements were made in our smaller temporary displays. Demonstrations of camouflage, and natural habitat displays were created. Microscope demonstrations were also set up for presentation of small invertebrate animals. A popular change in the program was a discussion with each tour group of the special techniques employed in obtaining all the display specimens.

OCEAN EDUCATION PROGRAM (OEP) AT UC-SANTA CRUZ

This program was developed to meet the expressed educational needs of the community and to increase public awareness of the fragility of intertidal communities.

School program

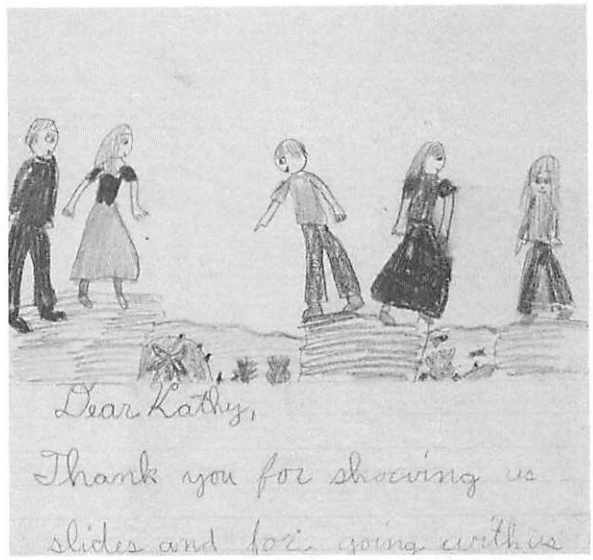
During the first year of OEP, the major focus was on serving the schools. Teachers of grades K through 12 were contacted primarily in Santa Cruz County. As our program became better known, classrooms from Santa Clara, San Benito, San Mateo and Monterey Counties participated; the program additionally had requests for services from groups as far away as Alameda, San Francisco, Fresno and Los Angeles Counties. From winter of 1977 (when the program actually got under way) through the summer of the same year, 113 groups totalling 3820 people were given guided walks and slide shows.

Curriculum development for teachers

Because the program was aimed at reaching school groups this first year, the development of associated curriculum materials was essential. An annotated bibliography, a field trip information sheet, a slide show and script and a tide pool kit were all developed or refined for school use. The kit includes pictures, artifacts, pressed seaweeds, a series of cards with games for students and suggestions for teachers. The two kits developed and the slide shows are housed and maintained at the City Museum.

Slide show

Since every class that participates must have adequate preparation for their trip to the tide pools, it uses a tide pool kit with slides and a script. For the majority of classes a specially trained university undergraduate



student intern visits the school and presents and narrates the slide show. Children are prepared for what they will see, and are introduced to basic ecological concepts through the slides and the use of games. For those classes which cannot be visited due to scheduling problems, the teacher can check out a tide pool kit (with slides) to prepare the class.

Publications

American Association of Zoological Parks and Aquariums, National Conference, Baltimore – Don Wilkie, program committee.

Association of Science Technology Centers, Lawrence Hall of Science, UC-Berkeley – Pat Kampmann, panel on education.

Environmental Symposium for teachers – Behavior and ecology of fishes from California and the Gulf of California.

National Marine Education Conference, Asilomar, California – Don Wilkie, speaker.

Revised educational materials at five grade levels.

Scripps Aquarium Newsletter.

Cooperating Organizations

Carlsbad School District, California

Chula Vista School District, California

Del Mar Library System, California

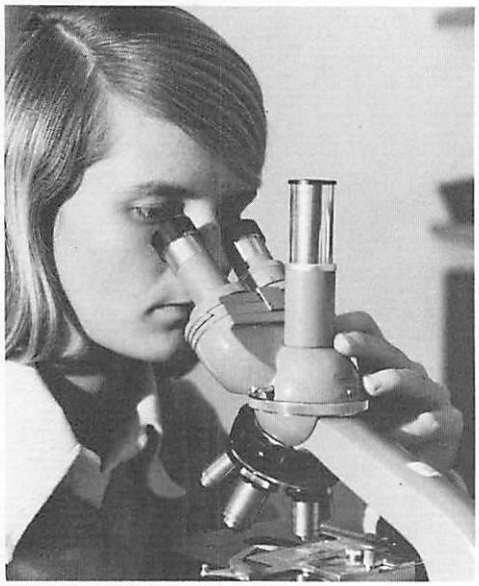
Los Angeles Bilingual Program

Marine Advisory Offices, UC-Davis and UC-San Diego (including 4-H programs).

San Diego City Schools, volunteer office

San Diego County Department of Education, Community Education Resources

Upward Bound and P.I.E. (Primary Interracial Education), Federal programs, Los Angeles, California



RESEARCH

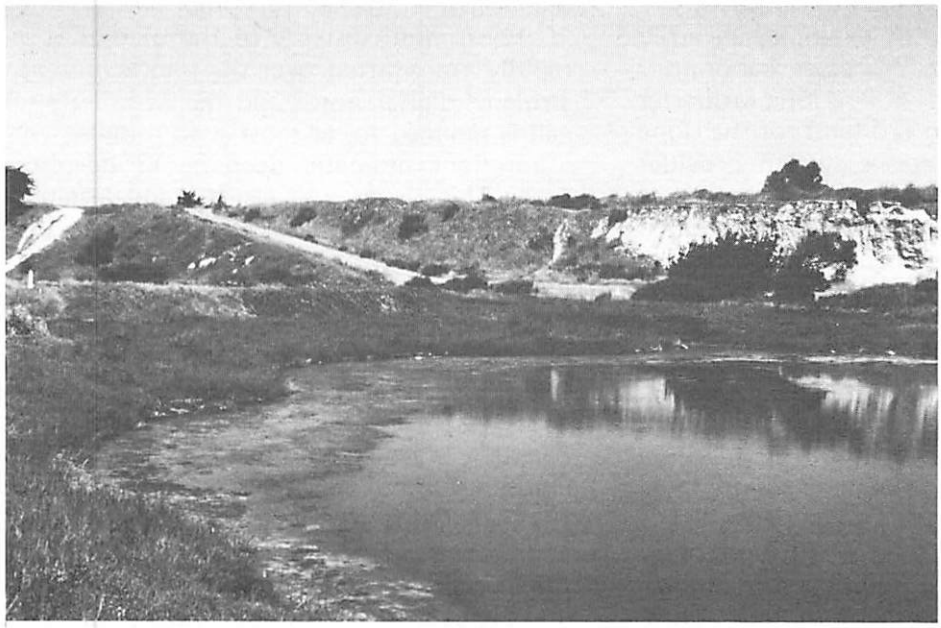
Although education and public service are vital aspects of the Sea Grant College Program, its 'raison d'être' lies in its research function, especially the ability to solve existing problems; to anticipate, and so prevent, new problems; and to reveal new opportunities. Most of our work is applications-oriented, yet a healthy balance is sought between applied research and basic research, with the latter continuing to be a prime University responsibility.

California is fortunate in having a high concentration of professional expertise distributed throughout the state on campuses of the University of California system, the State University system and private universities. The research reports that are presented in these pages issue from these diverse sources, although where applicable a high degree of coordination and/or collaboration of research efforts has been effected amongst the different research groups.

The 1976-77 University of California Sea Grant research program has been categorized in subject areas dealing with Coastal Resource Issues, Aquaculture (animal and plant), Fisheries, New Marine Products, and Energy Resources. Finally, there is the Rapid Response category, in which projects were established during the course of the year to meet needs unanticipated at the time of planning the research program.

COASTAL RESOURCE ISSUES

Sea Grant sponsored research aims at striking a proper balance between opposing interests: the forces that above all value commercial exploitation and 'growth', and those that consider conservation of our natural resources and the ecology as overriding concerns. In recognition of this conflict and the potential for irreversible damage to our coastal lands, a comprehensive coastal plan was delivered to the Legislature on December 31, 1975. Subsequently, there have been opportunities for Sea Grant to provide independent advice and assistance to the Legislature in its deliberations on the Coastal Act of 1976. In response to a request for assistance by the leadership of the Legislature, President Saxon has designated the Sea Grant College Program as the vehicle to coordinate the University's efforts in this direction. Liaison with the California Coastal Zone Conservation Commission and other agencies continues as an important program activity.



Coastal Engineering Data Network

San Diego
R/CZ-30

John D. Isaacs and Richard Seymour

As part of an endeavor to establish a methodology for obtaining economically a coastal wave climatology for California, a compact and economical slope array apparatus for measuring wave direction was evaluated at laboratory scale.

This program year, the first with Sea Grant funding, was the second year of operation of the Coastal Engineering Data Network. During this time two more stations were added to the system at Port Hueneme and Santa Cruz, both in cooperation with the Army Engineers. The Santa Cruz installation was of particular significance because it employed two major technological developments of this project: a compact slope array for measuring wave direction and a new data-handling system that stores the most recent 17 minutes of data at the remote station and rapidly transmits the information over the phone line when the central station computer calls. The station at Scripps Institution of Oceanography, installed last year, was reinstalled this year as a directional measuring station using the slope array.

Nearshore wave measuring arrays for scientific rather than engineering purposes are normally quite large. For example, an array installed by the Shore Processes Laboratory at Torrey Pines Beach is 400 m long (a quarter mile) compared to 6 m (20 feet) for the slope array. The Shore Processes system provides much more detail on the directionality of waves, providing an estimate of how much wave energy is arriving from each direction interval for each frequency interval. The slope array, because of its compactness, provides an estimate only of a single equivalent approach angle for each frequency interval. However, the analytical method employed is a very good estimator of the longshore momentum flux, from which a mathematically defined equivalent approach angle can be derived. The models for longshore sand transport presently employed provide for a transport rate proportional to longshore momentum flux. Thus, this method of measurement and analysis is particularly well suited to acquiring data from which sand transport rates may be estimated.

The slope array consists of four pressure transducers mounted at the corners of a square frame 6 meters on a side. Any three of the transducers are sufficient to estimate direction so that significant redundancy is provided, and if all transducers are operational, four independent estimates are obtained. The estimates of the longshore momentum flux are obtained by cross-spectral analysis of the differences between two orthogonal pairs of transducers.

Improved transmission rate of data

In the previously developed data transmission system, the central computer "listened" to each station for 17 minutes out of every 10 hours and recorded the wave records on magnetic tape. The new digital system has a memory bank for each transducer in the shore-based electronics box at the remote station. This memory contains 17 minutes of data and is updated once per second. When the central computer calls every 10 hours, the contents of the memories are rapidly transmitted over the phone lines as a string of digital words and the 17-minute toll call is reduced to, at most, two minutes with a resultant dramatic decrease in telephone costs. This system was designed and developed by project personnel and will be installed on all future stations.

The South Pacific Division of the Army Engineers has asked the project to develop a plan, based upon the results achieved here, for a major addition to the system involving more than 100 additional stations to provide a complete wave climatology for the California coastline. Funding has already been obtained from the California Department of Navigation and Ocean Development and the Army Engineers to add 10 more stations and to operate the system for another year. Four additional stations are under negotiation.

A transducer reliability problem, found to result from the manufacturing procedures involved with molding the transducer onto the cable, was discovered and considerable effort was required to determine the cause and the

solution. Redesigned transducers are now under test and appear to be satisfactory. However, the unavailability of transducers hampered the expansion of the network during this program year.

Monthly reports of data were provided in a timely manner to an ever-increasing list of users. The Army Engineers used these data for studies on shoreline erosion or navigational problems at Imperial Beach, Mission Bay and Oceanside, and the Port Hueneme data to evaluate a sand transport experiment. The Imperial Beach data also continued to support hardware evaluation experiments by the Tethered Float Breakwater Ocean Experiment. The Santa Cruz directional data will assist the Army Engineers with a difficult entrance dredging problem. The Imperial Beach and Oceanside data were used by Steven Pawka of SIO in his dissertation research on the effects of island shadowing on the coastal wave climate.

Findings of scientific interest

Although the system is designed primarily for the collection of engineering data, several findings of scientific interest were obtained. Among these was the discovery that a series of simple wave-gaging stations measuring only wave height and arranged along a coastline with complex offshore bathymetry can provide reasonable estimates of deepwater swell directions. This approach to remote sensing of deepwater waves, called an incoherent gradient array, is presently being explored using the four San Diego County stations to form the array. The station at Ocean Beach is subject to large waves in relatively shallow water. Tidal elevation changes provide the equivalent of moving the wave gage on- and offshore. More than a year's data from this station are being analyzed to provide information on the nonlinearity of shoaling waves as defined by the departure from a Gaussian distribution of elevations. Further analysis is under way to study the long-period (greater than 18-second) precursor waves which signal the arrival of swell from major storms in the Pacific Basin.

Publications

Seymour, R.J., Defining the wave climate for a harbor, Ports '77 Conference, Fourth Annual Symposium of the Waterway, Port, Coastal and Ocean Division of the American Society of Civil Engineers, Long Beach, California, March 1977.

Idem, Measuring the nearshore wave climate: California experience, Ocean Wave Climate Symposium, National Ocean Survey, NOAA, Washington, D.C., July 1977; in press.

Seymour, R.J., and A.L. Higgins, A slope array for estimating wave direction, Proceedings of a Workshop on Coastal Processes Instrumentation, June 16, 1977, La Jolla, California, Sea Grant Publication, in press.

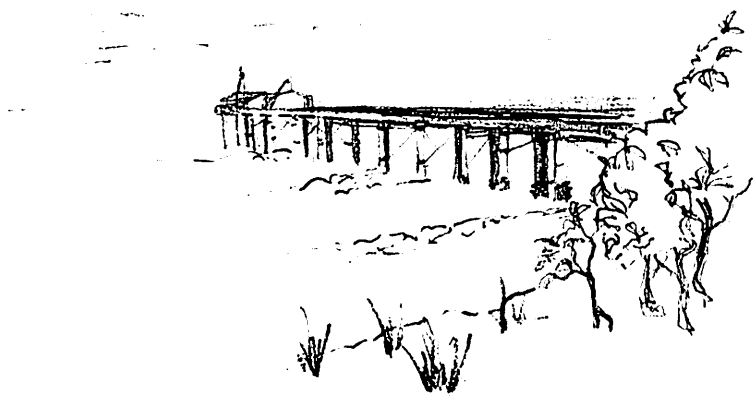
Seymour, R.J., M.H. Sessions, S.L. Wald, and A.E. Woods, Coastal Engineering Data Network Second Semi-Annual Report, July 1976 to December 1976, Institute of Marine Resources, University of California, IMR Ref. 77-103, Sea Grant Publication No. 56, January 1977.

Idem, Coastal Engineering Data Network Third Semi-Annual Report, January 1977 to June 1977; in press.

Cooperating Organizations

California Department of Navigation and Ocean Development

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



Tilting Spar Directional Wave Sensor

San Diego
R/CZ-40

Douglas L. Inman and Robert T. Guza

A theoretical model has been developed for an optimum response of a tilting spar to linear surface waves. The optimization scheme provides criteria for selecting the physical design parameters of diameter, weight and mooring depth which allow a response over a range of frequencies free of contamination from nonlinear effects of drag. According to these criteria, several spars were built and field tested off Torrey Pines State Beach, California. The spars were found to resolve a mean wave direction accurately between wave periods from 5.0 to 20.0 seconds.

The objective of this research has been to perfect a compact, low-cost, easily installed and maintained directional wave sensor suitable for deployment along the nation's coast lines for monitoring wave climate. The tilting spar wave energy-directional sensor consists of a surface piercing buoyant spar attached to bottom weights by a universal joint that permits response to wave motion. The motion of the spar, sensed by two accelerometers, gives wave direction, while a pressure sensor provides wave energy. The data may be transmitted to shore by telemetering or by bottom laid cable.

There has been an ever-increasing need for such coastal wave climate in all aspects of coastal planning, ranging from the assessment of environmental impact statements pertaining to beach erosion and harbor siltation to the siting of new LNG terminals, coastal refineries and power plants. The numerous marinas and harbors which line the California coast, requiring millions of dollars each year in dredging maintenance, attest to the fact that these decisions have not in the past been based on adequate wave statistics. Unfortunately, most previous technology for gathering these wave data is precluded from such broad-range application. For example, line arrays of bottom-mounted pressure sensors can gather extremely accurate statistics on wave height and direction but are difficult to install and are prone to frequent breakdown because of excessive complexity. Remote sensing of the sea surface by airborne radar is prohibitive in cost, with data acquisition limited by aircraft availability and endurance. Finally, the numerous deep water wave observations from ships and wave rider buoys, as well as those from shore observers, are inaccurate in directional and/or frequency resolution.

The tilting spar employed in the Shelf and Shore (SAS) System,* developed under previous Sea Grant support, offers a viable alternative to these technologies. The SAS spar is a buoyant, air-filled filament glass pipe which houses a telemetry package and antenna in the portion of the spar extending above the free surface. Throughout five years of field testing, the spar has proven itself to be a secure structure for instrumentation in nearshore waters, repeatedly operating through storm conditions with waves as high as 3 meters.

The tilting spar directional wave system can be used in either of two modes for data link to shore: by cable, or by radio telemetry. The system could be manufactured in quantity in the cable mode of data link at an estimated unit price of $5500 with a 350 meter length cable. In the telemetry data link mode the estimated unit cost is $6000, including the shore receiver.

The pair of orthogonal accelerometers in the directional package permits alignment, maintenance and trouble shooting of all instrumentation to be accomplished quickly and with a high degree of accuracy from a small boat. With the accelerometers, both the history and the spectrum of the motion induced in the spar by the waves can be determined. The fundamental task of this research was to learn how the physical parameters of the spar (size, shape, weight, and mooring depth) should be selected so that the motions excited in the spar are representative of the wave motion at a given depth of water. When this is accomplished, the spar motion can be

*Lowe, R.L., D.L. Inman, and B.M. Brush, 1972, Simultaneous data system for instrumenting the shelf. Proceedings 13th International Conference on Coastal Engineering, Amer. Soc. Civil Eng., Vol. I, pp.95-112.

used directly to infer the desired wave statistics.

A theory was developed for an optimum response of the spar (Jenkins and Inman, manuscript in preparation). The optimization was based on obtaining a response that resulted in zero net drag forces acting over the length of the spar. These drag forces result from relative motion between the spar and the water. They are particularly undesirable because they are non-linear, causing the spar to move out of phase with the water motion, and inducing secondary higher frequency oscillations. To eliminate net drag forces, it was shown that the spar should be made to follow the horizontal wave motion at a particular depth, which is referred to here as the null point of the drag moment (Fig. 1). The moment about the bottom due to drag resulting from the relative motion above the null point exactly cancels the drag moment from opposing relative motion below the null point. The depth of the null point varies with the vertical rate of decay of the wave motion. Accordingly, the null point of the drag moment was found to depend upon the wave length (or frequency) encountered at a given mooring depth, h, as in Fig. 2.

It can be shown that the spar must have no net buoyancy if it is to follow the wave motion at the drag moment null point over all possible incident wave frequencies. However, given that a certain amount of buoyancy must be retained to keep the spar upright, in theory the most practical alternative is to keep the center of buoyancy as close to the bottom as possible, and operate at a mooring depth comparable to the incident wave length. The minimal buoyancy which must be retained, together with the maximum mooring depth acceptable for a given location, essentially define the low-frequency cutoff which is found to be $\sigma = \sqrt{\epsilon g/h}$, where σ is the radian frequency for the incident wave, g is the acceleration of gravity, h is the water depth, and $\epsilon = (\rho_s - \rho)/\rho$ is the ratio of the density difference between the water, ρ, and the spar, ρ_s, to the density of the water. A further consequence of buoyancy is the phenomenon of a natural frequency at which the spar can be excited to excursions which greatly exceed those of the water motion at the null point. Fortunately,

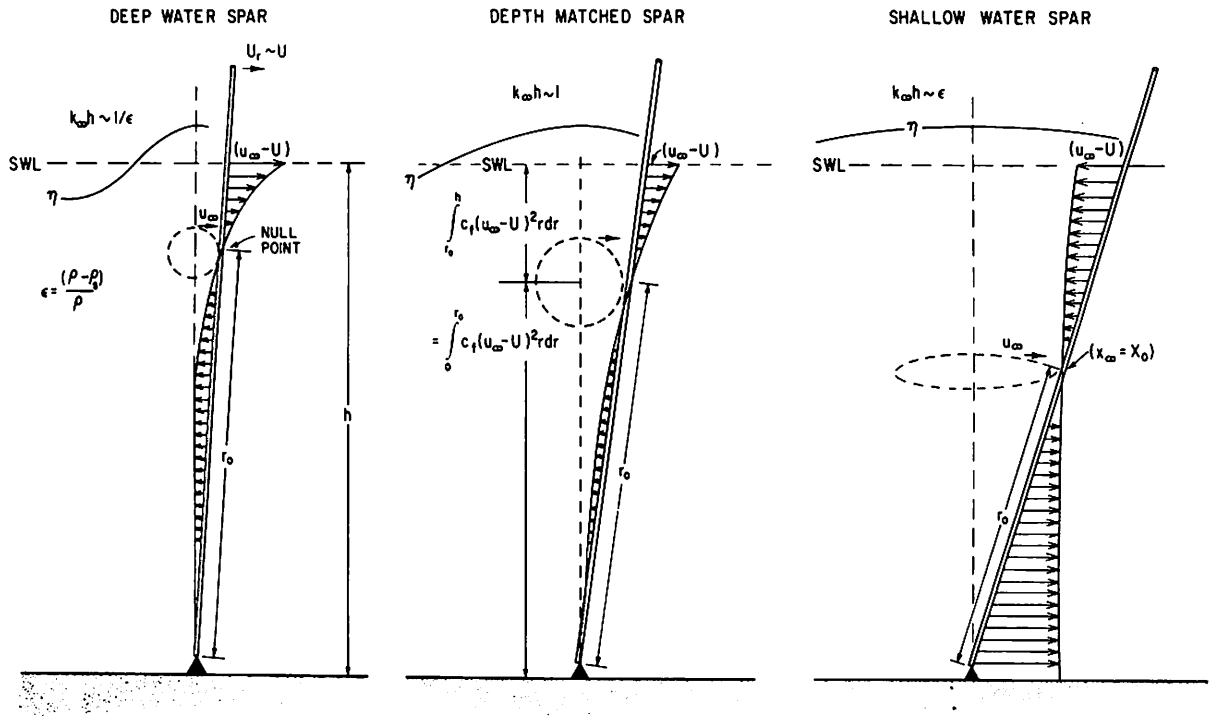


Fig. 1. Vertical distribution of the relative velocity, $(u_\infty - U)$, gives rise to a zero net drag moment when the spar follows the horizontal wave particle excursions, x_∞ at r_0, the drag moment null point. Variation of the relative velocity distribution with wave frequency gives rise to three distinct scale regimes having different null points

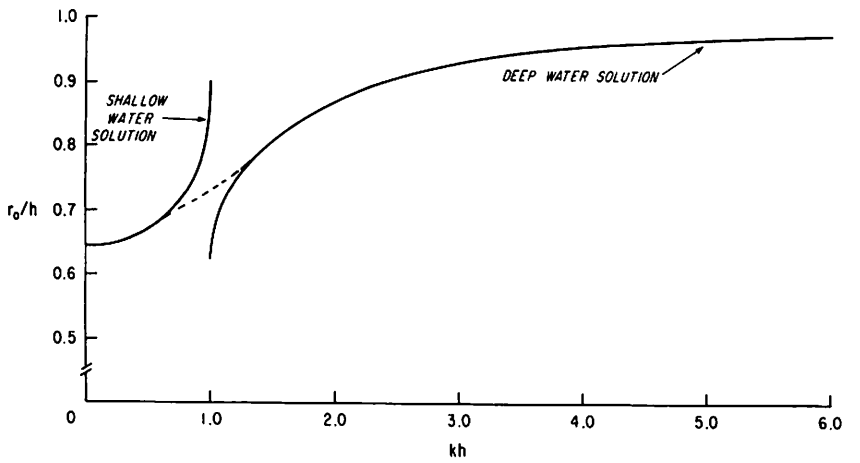


Fig. 2. Asymptotic solution for the drag moment null point, r_o, as a function of the incident wave number, k = 2π/wavelength, encountered at a mooring depth, h

the design criteria which lead to a low cutoff frequency, namely relatively small ϵ and large h, were also found to enhance a condition of overdamping, which suppresses resonance near the natural frequency.

Finally, the high-frequency response cutoff for the spar was found to be limited by the vortex-shedding frequency resulting from wake formation at depths where significant relative motion exists between the spar and the water. Vortex shedding introduces spurious longshore energy into the accelerometer records at the shedding frequency and can be displaced to frequencies beyond the regime of wind waves by using relatively small spar diameters. The radian shedding frequency, σ_s, is found to be given by the Strouhal relation $\sigma_s = 0.1\ \sigma d_o/D$, where $\sigma = 2\pi/T$ is the radian frequency of the waves, d_o is the orbital diameter at the null point, and D is the spar diameter. However, the optimum response theory places a limit on the smallest permissible spar diameter as $D = -d_o/\log \epsilon$, before drag effects contaminate the response.

With the above expectations from theory, a weakly buoyant ($\epsilon = 0.4$) "design" spar at a depth of 15 meters was field tested in March and April, 1977, off Torrey Pines State Beach, California, and compared with an off-design ($\epsilon = 0.6$) spar in 10 meters. Both spars were referenced to a five-element line array of bottom-mounted pressure sensors located at the 10 meter depth. The line array gave estimates of wave direction spectra which served as a ground truth against which the performance of the two spars could be evaluated. Mean wave directions were calculated from the line array by averaging over the direction spectra representative of 34 minute length records with 32 degrees of freedom. Ground truth mean wave directions appropriate for evaluating results from the design spar were obtained after shoaling the wave direction spectra out to 15 meters depth before averaging over direction for a mean value. Mean wave direction estimates were calculated from the motion of the two spars by taking the vector sum at each frequency of the rms amplitudes from the orthogonal pair of accelerometers contained in the telemetry package. It was necessary to correct these rms amplitudes for the component of gravity superimposed when steady currents give the spars a non-zero mean tilt angle, thereby tilting the axes about which the accelerometers sense the resulting motion.

A band-by-band comparison of the mean directions obtained in the above manner from the 15 meter "design" spar and the array appear in Fig. 3 for a 34 minute run during a local storm on 25 March 1977. Agreement in mean direction between the design spar and the array appears quite good over the range of periods which the linear ground truth array can resolve, 6 to 18 seconds, especially under the principal spectral peaks. Furthermore, the accelerometer spectra are found to reproduce the major features of the pressure spectra

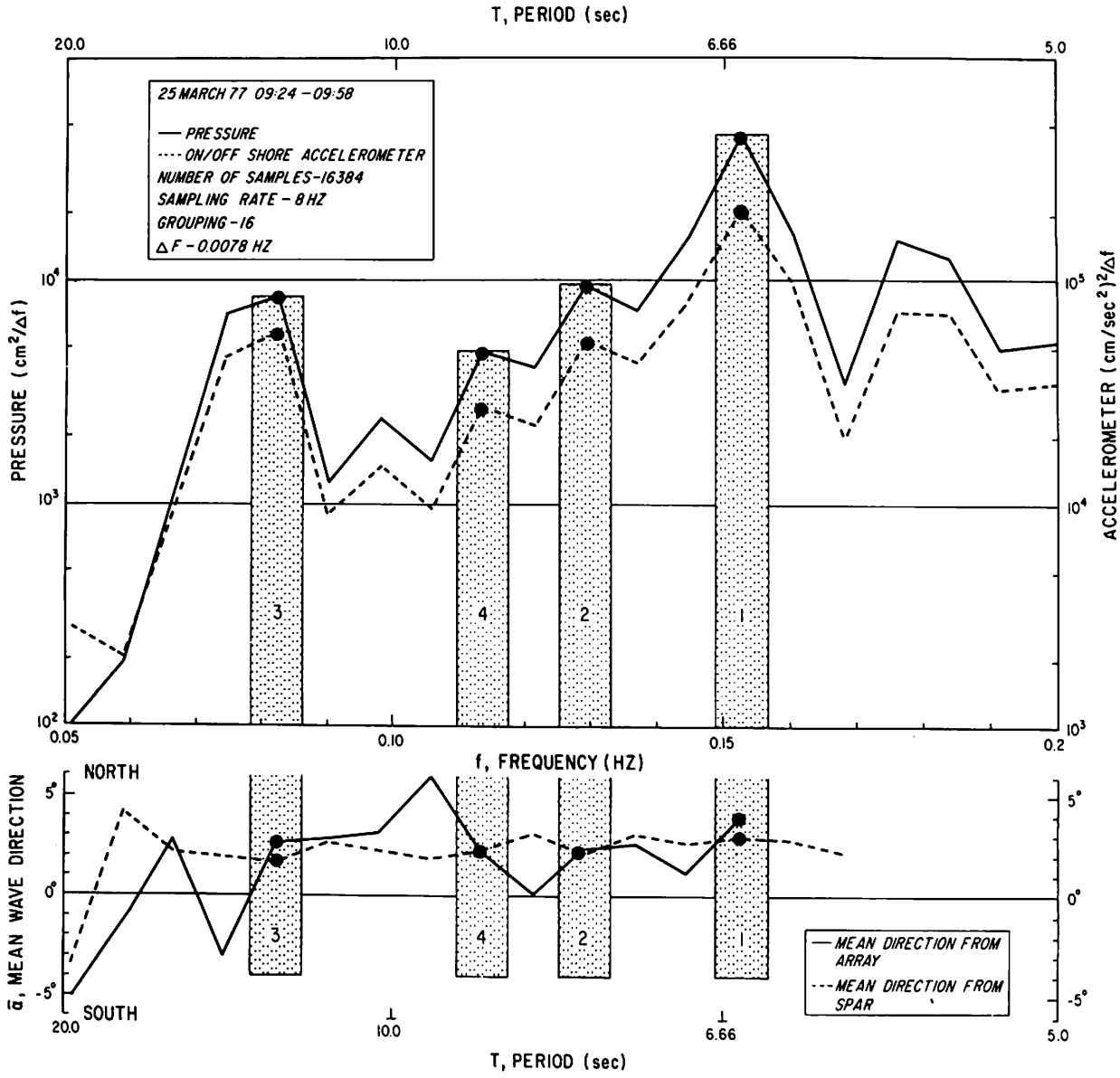


Fig. 3. ABOVE. Band-by-band comparison between the autospectra of the pressure with those of the on/off shore accelerometer in the design spar moored in 15 meters of water. BELOW. Mean wave direction obtained by averaging the direction spectra from a 5-element line array compared with mean wave direction from the vector sum of the rms amplitudes from an orthogonal pair of accelerometers in the design spar. Direction spectra from array were measured in 10 meters and shoaled out to 15 meters for comparison with the design spar

with the appropriate relative energy. Mean wave directions from the design spar and the array for principal spectral peaks from a number of varied runs are compared in the Table. These results show close agreement in mean direction even for highly spread, multi-modal direction spectra.

The range of frequencies over which the design spar can gather wave direction information is limited by the range over which it will respond in phase with the horizontal wave particle motions. The study showed that a tilting spar directional wave sensor could be designed for a variety of frequency ranges by adjusting the buoyancy, mooring depth, and diameter of the spar. The experiments established the useful range for this particular spar to be from 5.0 to 20.0 seconds. Undoubtedly, the design spar gave reliable directional data to shorter periods, but there was no ground truth for evaluating direction for periods below 5 seconds. A pressure sensor mounted

MEAN DIRECTION COMPARISON FOR PRINCIPAL SPECTRAL PEAKS

Run	Peak	Period (sec)	Mode	5-Element Array Mode Direction	5-Element Array Mean Direction	Design Spar Mean Direction
16 March 77	1	14.8	1	18.5°S	21.6°S	20.9°S
17:32	3	11.0	1	37.5°N	2.9°N	3.1°N
*Mean Currents:			2	6.5°N		
1.5 cm/sec On			3	40.5°S		
2 cm/sec S.	2	7.7	1	12.5°N	7.2°N	7.1°N
			2	7.5°S		
			3	43.5°S		
25 March 77	3	12.0	1	7.4°N	2.7°N	1.6°N
9:24	4	8.8	1	10.8°N	2.1°N	2.2°N
Mean Currents:			2	9.9°S		
1 cm/sec On			3	22.2°S		
6.2 cm/sec S.	2	7.7	1	8.6°S	2.3°N	2.1°N
			2	14.1°N		
	1	6.5	1	17.1°N	3.9°N	2.9°N
			2	6.7°N		
			3	6.0°S		
			4	15.3°S		
25 March 77	2	12.0	1	7.4°N	2.6°N	2.7°N
9:58	3	10.1	1	9.7°N	1.5°N	3.7°N
Mean Currents:			2	11.2°S		
1 cm/sec On	1	6.5	1	14.7°N	2.2°N	5.2°N
6.2 cm/sec S.			2	10.6°S		
			3	24.6°S		
25 March 77	3	12.0	1	7.3°N	2.6°N	1.4°N
10:32	4	10.1	1	8.5°N	1.5°N	1.8°N
Mean Currents:			2	11.2°S		
0.5 cm/sec Off	2	7.3	1	16.3°N	2.4°N	2.0°N
8.5 cm/sec S.			2	5.6°N		
			3	23.9°S		
			4	13.2°S		
	1	6.5	1	14.7°N	2.1°N	2.0°N
			2	10.6°S		
			3	24.5°S		
29 March 77	3	14.8	1	6.3°N	4.3°S	2.2°S
11:21	1	10.1	1	9.8°N	4.7°S	1.7°S
Mean Currents:	2	8.2	1	5.0°N	5.9°S	2.6°N
3 cm/sec On			2	13.2°S		
3 cm/sec N.						
29 March 77	2	14.8	1	3.7°N	1.1°S	5.4°S
11:55	1	11.0	1	9.9°N	3.4°N	2.4°S
Mean Currents:			2	5.1°S		
3.3 cm/sec On	3	7.3	1	16.5°N	5.1°N	2.1°S
2.9 cm/sec N.			2	12.1°S		
29 March 77	2	14.8	1	7.7°S	5.2°S	3.4°S
12:29	1	11.0	1	6.1°N	0.3°N	0.4°N
Mean Currents:	3	8.2	1	10.8°N	5.2°N	0.5°N
3.3 cm/sec On			2	7.5°S		
2.2 cm/sec N.	4	6.5	1	17.5°N	3.1°N	5.6°N
			2	12.0°S		
			3	9.2°N		
31 March 77	2	14.8	1	14.1°S	13.0°S	10.9°S
12:26	1	11.0	1	9.9°N	4.4°N	3.5°N
Mean Currents:			2	7.6°S		
2.6 cm/sec On	3	8.8	1	10.9°N	6.3°N	2.8°N
2.5 cm/sec S.						
31 March 77	2	13.3	1	16.7°S	11.0°S	12.4°S
13:01	1	11.0	1	10.0°N	2.9°N	2.2°N
Mean Currents:			2	6.4°S		
3.3 cm/sec On	3	7.7	1	14.4°N	7.2°N	0.7°N
3.0 cm/sec S.			2	8.6°S		

*"N", "S", "On", "Off", signify longshore to the north or south and on/or offshore currents.

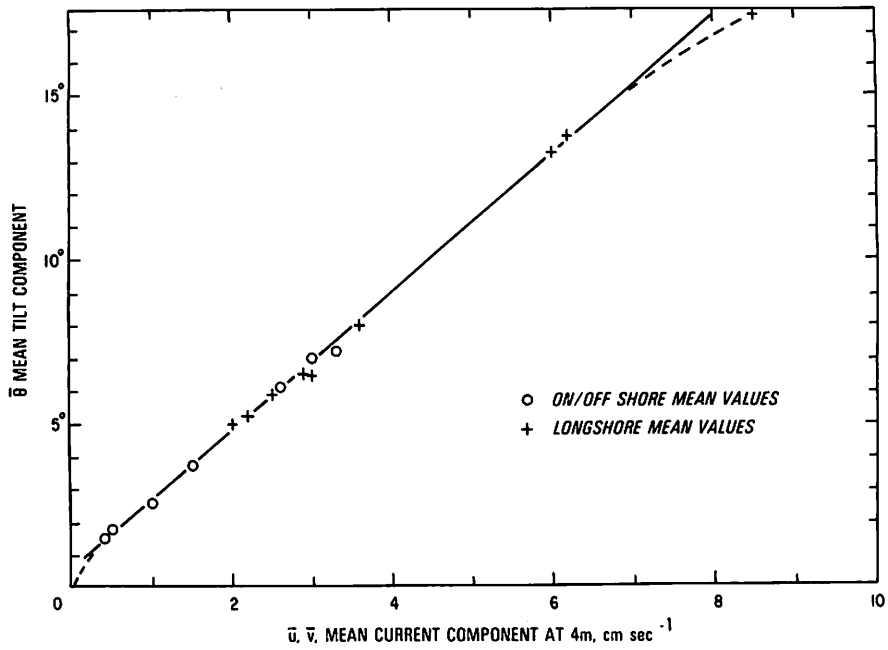


Fig. 4. Onshore and longshore zero frequency response of the 15 meter design spar to onshore and longshore steady currents measured at 4 meters depth. Mean tilt and currents taken over 34 1/2 minute records between 16 and 31 March 1977

near the null point of the spar could extend the utility of directional data into the extreme high frequency portion of the spectrum.

About 60 per cent of the mean wave direction estimates derived from the off-design, highly buoyant spar in 10 meters of water also compared favorably with those measured by the line array. When estimates from the 10 meter spar did not compare well, the frequency band for the direction in question appeared at a small integer multiple of significant low-frequency energy.

Although the weakly buoyant deep water spars appear less sensitive to resonance and frequency contamination, a possible limitation to their application may be in locations where strong steady currents ($>$ 50 cm/sec) would lean them over at large constant tilt angles. However, in moderate steady currents ($<$ 20 cm/sec), the zero frequency response or mean tilt of the spar may serve as a useful measure of the vertical average of these currents. Figure 4 shows a systematic variation of the mean tilt angle in the onshore and longshore directions with the mean onshore and longshore currents measured 4 meters below mean sea level during the 16-31 March 1977 runs. These currents were of tidal periodicity, lacking significant vertical structure other than a bottom boundary layer. The effect of baroclinic motions during warm summer months on variations in mean tilt angle with mean current, however, requires further study.

Thermal Variability in Coastal Waters in the Southern California Bight

San Diego
R/CZ-31

Clinton D. Winant

Modern use of the coastal environment includes using the ocean as a heat exchanger for large conventional and nuclear power plants.

This project is a statistical study of the natural thermal variability in the coastal waters of the Southern California Bight. Man's impact in the area of our continental shelves is increasing rapidly. Coastal systems such as the San Onofre Nuclear Generating Station (SONGS) indicate the growing need to estimate the perturbing effect such installations may have upon the natural status of oceanic variables. Present numerical modeling schemes designed to evaluate the impact of ocean thermal outfalls are deficient in their descriptions of ambient thermal (and mixing) conditions and thus cannot be expected to provide realistic quantitative estimates of the perturbing effects of such outfalls.

The objective of this particular study is to provide a more detailed description of the natural thermal variability in southern California coastal waters that may be used as initial input to large numerical routines to refine estimates of ambient mixing conditions in these waters. During the past year our intent was to accumulate ocean temperature data from a variety of spatial positions along the continental shelf, and at many different depths. Since the data exhibit marked seasonal variability, we felt that at least two-year long data sets would be required to describe variability on a seasonal time scale. To this end, we have acquired one set of year-long records from moorings in the vicinity of SONGS in cooperation with the Marine Review Committee of the California Coastal Zone Commission. We have also initiated a data gathering program sponsored by the National Science Foundation, consisting of three moorings on the continental shelf adjacent to the city of Del Mar about 45 km south of SONGS. This effort will continue for one year (1977-78) and will provide temperature data at eight spatial positions for one seasonal cycle. These data sets are to be complemented with ocean surface and bottom temperatures monitored at the end of the Scripps Institution of Oceanography pier which is located approximately 12 km south of the Del Mar instrument array. Our efforts to date have been spent in forming the data sets from the three aforementioned geographical locations, and such activity will continue into 1978.

Statistical analysis of data

Future work will concentrate on the statistical analysis of these data. These efforts will be directed specifically toward the redirection of data catalogs into statistical quantities that will be directly applicable to larger numerical simulation models. These include estimates of spatial temperature variability (coherences) as well as estimates of seasonal means, variances, and power spectral density (variance as a function of frequency). This information may be useful to both coastal zone modelers and scientific researchers in the field. Measurements of coastal currents will also be available to aid in matching certain aspects of temperature variability with dominant forcing processes on the continental shelf, such as local winds and tides. Our eventual goal is a complete description or understanding of the coastal system as a whole which may be approached by careful observation and analysis of the system's state variables.

Cooperating Organizations

California Coastal Zone Commission, Marine Review Committee, National Science Foundation, Goleta, California

Internal Waves over Shelf and Canyon

San Diego
R/CZ-32

C. S. Cox

In this project, current meter data were analyzed to determine the coastal internal wave climate.

There exist several sets of current meter data which are suitable for the study of the coastal internal wave climate. Analysis of such data was used to determine the energy flux input towards the coast as well as some factors modulating the energy flux. An interesting result was that the total energy flux input into the coastal zone was an order of magnitude larger than could be accounted for by using a Garrett and Munk model for the deep sea.

A particularly important data set was measured during the JOINT I project (sponsored by National Science Foundation through the International Decade of Ocean Exploration and the Coastal Upwelling Ecosystems Analysis programs). The array used was designed to monitor low-frequency changes in the current and hydrographic regime in the coastal zone with strings of current meters covering the water column over the continental shelf and slope and near the shelf break. This sort of array is also highly suited for the study of the internal wave climate in the coastal zone.

Results of analysis

There were several interesting results from the analysis of the JOINT I data. The first is that it was possible to estimate the energy flux incident from the deep sea. This flux, approximately 10^3 Joules/sec per meter of coastline, is not very large compared with typical tidal dissipations. However, it may be a significant input to mixing processes which are required to replenish nutrients in the euphotic zone. A second important observation was that internal wave energy dissipation becomes dominantly important in areas where the internal wave amplitudes grow to a size comparable to the depth. As internal waves progress towards the shore, their amplitude increases as the depth decreases, so that at some point, the amplitudes must become comparable to the depth. At this critical point, dissipation must remove enough of the wave's energy so that the amplitude does not become larger than this critical fraction of the depth. In the area where the JOINT I project took place, it appeared that most of the energy dissipated inside a band within a few kilometers of the shelf break. In the entire zone where the array was placed, the regime appeared to be one of internal waves progressing shoreward and dissipating near the shelf break and closer to shore. Generation of internal waves did not appear to be an important factor. This raises the question of where the observed energy flux comes from.

Publications

Gordon, R. Lee, Internal waves within submarine canyons. Presented at AGU meeting, December 1976.

Idem, Internal wave climate near Northwest Africa during JOINT I. Presented at AGU Spring meeting, June 1977.

Coastal Wetlands Management

California's coastal wetlands are rare and threatened, yet remain little understood. The following three research projects aim at increasing our understanding. A main objective was to provide the biological data for a realistic characterization of these resources – how they function, and how they respond to disturbance – in order to assist in coastal zone planning and management. By conducting a basic biological inventory and an analysis of ecosystem function in Mugu Lagoon and the Tijuana Estuary – the closest to pristine lagoon-salt-marsh ecosystems remaining in southern California – and comparisons with other localities, it appears possible to predict the probable consequences of system modifications and to provide the basis for designing management programs that are most likely to preserve or enhance the natural values of coastal wetlands. Another research avenue concerns the engineering problem of artificially opening and maintaining inlets between the ocean and lagoons or estuaries to provide for water exchange.

BIOLOGICAL CRITERIA

Project Leaders: R. Holmes, C. Peterson, and C. Onuf

We have spent the first year of our wetlands management project:

1. Estimating biomass and productivity of two of the three dominant plant types in the lagoon-salt marsh ecosystem.
2. Compiling a general inventory of benthic and epibenthic invertebrates, and conducting growth and disturbance experiments on some of them.
3. Censusing birds every 10 days; beach seining for fish each month; making feeding observations on shore birds; and analyzing gut contents of fish and some invertebrates. Our intention is eventually to make quantitative estimates of relative contributions by the different types of plants to total primary production for the system. By examining the gut contents of important filter feeders and comparison with samples of suspended organic matter taken in the same localities, we hope to qualitatively evaluate whether organic material from different sources is utilized indiscriminately or selectively; that is, to determine whether some sources may be much more important than productivity estimates indicate. We similarly intend to combine the results of gut content analysis of fish and feeding observations on birds with the general invertebrates sampling to relate availability to actual importance in support of the high-level consumers.

1. Primary productivity

Marsh plants. Twenty 1/16 m^2 plots have been harvested monthly since January 1977. Concurrently, the growing tips of 50 plants each of six of the eight species so far found in the harvest samples have been measured. In addition to the traditional treatment of harvest samples for estimating productivity (sorting according to species and green-live-dead, then drying and weighing), all growing tips of all species have been measured in the same way as the tagged plants. As well as the normal procedure of calculating production as the difference between the maximum and minimum standing crops over the year summed for all species, we have generated a truer estimate by combining size-frequency distributions of growing tips from the harvest samples with size vs. growth relationships determined from the tagged plants. We decided that this laborious check on the harvest method was necessary because, unlike the east coast marshes that have been studied, this marsh and others in southern California are dominated by perennials that have at least some active growing tips year-round. The turnover of green material may well be much larger than the maximum net change over a year would indicate.

Preliminary analyses January to June, for three species are now complete. In the five months of maximum net change, the more direct estimates (growth per growing tip X number of growing tips) were already 1.76, 2.53 and 1.8. times higher than maximum net change for *Salicornia virginica*, *Jaumea carnosa*, and *Limonium commune*, respectively. These three species accounted for

65 per cent of the biomass of growing tips over this period and ranked 1, 2, and 4 in this regard. Since the biomass of growing tips has remained high but increased little at least through August, it is likely that the two estimates will diverge more before the year is complete. It is worth noting that the maximum standing crop in this system (<300 g/m^2 green) is low compared to *Spartina*-dominated marshes (often exceeding 2000 g/m^2 green), although high turnover in the former may reduce the difference in productivity.

Epibenthic algae. Estimates of epibenthic algal productivity are highly variable. This is probably because of spatial patchiness and the short duration of bloom conditions within a patch, even on a substrate that appears uniform. At Mugu Lagoon the bottom ranges from coarse sand to mud. We have adopted the sledgehammer approach to contend with these multiple sources of variability: take big samples often. The variability remains, but as the number of samples mounts, we hope that gross patterns will become more credible. Our estimates for Mugu Lagoon tend toward the high end of published productivity values for the same time of year in New England, Georgia, Scotland and Denmark (lake). Thus we have a suggestion that at the level of primary production, Mugu Lagoon may differ from east coast systems in having a relatively unproductive marsh but a relatively highly productive assemblage of epibenthic algae. We also are estimating the standing crop of microalgae by determining pigment concentrations of acetone extracts. We hope that these data may be useful in interpreting the distributions of invertebrates or their rates of growth.

2. Invertebrates

The sampling program for invertebrates began in January 1977 and will yield basic information on the distribution and abundance of what is available as food for fish and birds. Experiments in which two species of clams have been maintained at different densities both alone and together are yielding information on growth and competitive interactions that are highly relevant in evaluating their suitability for a sustained fishery. Apparently each species (*Protothaca staminea* and *Chione undatella*) is sensitive to crowding by its own kind but shows no response to similar levels of crowding by other species. The possibility that these two filter feeders select different food types is presently under investigation. The effects of the physical disturbance of clam harvesting are being tested by determining the growth rates of different sets of clams that are dug up and replaced at different frequencies. Results are not yet available.

3. Birds and fish

Birds. The censuses at 10-day intervals of water-related birds now cover the whole year October 1976 to September 1977. Shore birds were most abundant (64 per cent of all sightings) followed by gulls (11 per cent) and fish-eating birds (9 per cent). In addition to the expected pattern of large numbers during fall and spring migrations and relatively high numbers throughout the winter, two other patterns have emerged: over the year as a whole the large, probing shore birds (dominated by the marbled godwit, 29 per cent of all sightings of birds) occur most frequently at the sandy end of the lagoon; whereas, the small, top-feeding shore birds were more commonly sighted toward the muddy end. In addition, there is a striking seasonal difference in where the shore birds occurred. For July to December and January to June, respectively, 42 per cent compared to 10 per cent of top-feeders were seen at the sandy end. Similarly for the probers 61 per cent compared to 48 per cent were in the sandy end for the two periods. We do not yet know whether this change in the location of the birds is related to seasonal changes in abundance of prey or to another cause, perhaps the availability for feeding of intertidal areas in the daylight hours.

Fish. Of the 6862 fish so far caught at our four monthly beach seining stations, two species top smelt *(Atherinops affinis)* and shiner surfperch *(Cymatogaster aggregator)* have accounted for 78 per cent of all individuals caught. At the other extreme, 17 of the 34 species have numbered fewer than 10. Five species have been caught in all eight months (but not the first and fifth most abundant species). Seven of the eight species represented by more than 50 individuals were caught at all four stations; however, five of those seven were at least twice as abundant at one station as any other. Thus, although it appears that the abundant species tend to be in the lagoon year-round (except shiners, the

most abundant species) and occur throughout it, most are concentrated in particular areas. Top smelt and shiner surfperch are almost certainly important prey for the fish-eating birds and perhaps other fish. California halibut *(Paralichthys californicus)*, fourth in abundance in our sampling, is the only commercially caught fish. We do not know whether this lagoon population contributes to commercially fished stocks, only that the individuals which we have caught are young. Our attempts to relate the activities of birds and fish to the rest of the biota are as yet too preliminary to report.

EFFECTS OF DISTURBANCE ON ESTUARINE FUNCTIONING

Project Leaders: Joy B. Zedler and David A. Mauriello

Proper wetland management requires a knowledge of ecosystem functioning plus accurate predictions of how various management alternatives affect that functioning. Due to a lack of such information, particularly for southern California wetlands, the well-studied eastern U.S. estuaries have been used as a data base from which to extrapolate effects of altering Pacific Coast wetlands. In this study we have found significant differences between the Tijuana Estuary and eastern U.S. estuaries, demonstrating that management recommendations here should not be based on data or relationships found on the Atlantic or Gulf of Mexico Coasts.

The understanding of wetland functioning under natural and disturbed conditions is the goal of this project. Together with Holmes and Peterson at UC-Santa Barbara, we are examining the food web dynamics of the intertidal salt marsh and channel communities. Our emphasis is on the base of the food chain, the wetland vegetation. Wetland plants respond rapidly to changes in topography (brought about by dredging and filling), to eutrophication (caused by changes in surrounding land use and water management), and to recreational use (trampling). These impacts on the vegetation affect animal populations whose habitat cover and food availability are altered.

Wetland ecosystems consist of several types of habitat and hence several biological communities. This study was divided into four parts to determine: 1) the dynamics of salt marsh vascular plant producers, including productivity and decomposition rates; 2) the composition and productivity of algal mats within the salt marsh); 3) productivity of channel phytoplankton and benthos; and 4) movements of materials between the upper channels, lower channel areas, and the ocean entrance. During the first year, our goal has been to study these characteristics in the Tijuana Estuary, one of the least altered wetlands along the San Diego County coast. In contrast to many other southern California wetlands, the Tijuana Estuary remains open to the sea throughout the year, is influenced by daily tides, maintains good circulation, and has a diverse flora and fauna.

Salt marsh vascular plants

A major contrast between eastern and western salt marshes is the relative importance of cordgrass (*Spartina* species) and succulents (*Salicornia, Suaeda, Batis,* and others). Cordgrass is limited and succulents are dominant in western marshes, while the reverse is true in the east. Where it occurs on the West Coast, cordgrass is highly productive. Frequent harvests of the salt marsh vascular plants provided basic information about the standing crop and productivity of 13 species over a wide range of habitats (denoted by relative elevation). Cordgrass, which dominates the low marsh habitat, is the most productive species per unit area (Fig. 1). Succulents, found at higher elevations, have lower per unit area productivities. However, since the total area of upper elevations is large, the succulents contribute more to the total salt marsh food base than does the low marsh cordgrass (Fig. 2).

Cordgrass and succulents differ not only in abundance and productivity, but also in decomposition rates, a factor of importance to the wetland food chain. Most consumption of salt marsh vascular plants appears to occur after some degree of decomposition, so that plants enter the food chain as detritus rather than green foliage. The decomposition process is complicated, with microbes and detritivores interacting to break up the large fibrous vascular plants, thereby making them edible and more nutritious.

Our studies of the disappearance of plants from litter bags show that cordgrass decomposes slowly (Fig. 3). Its edible food is released slowly as detritus (particulate carbon).

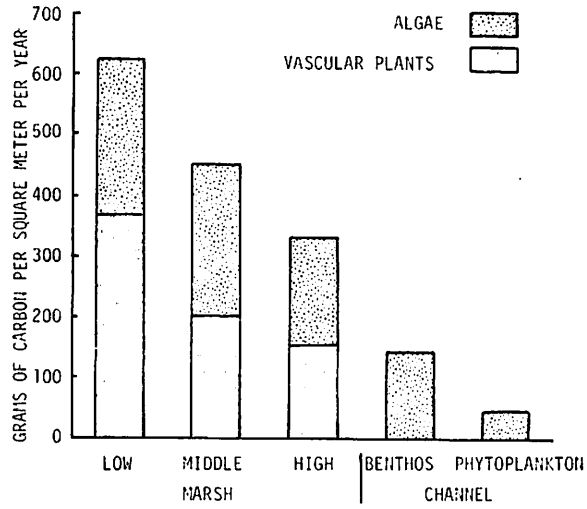


Fig. 1. Net annual productivity for five wetland habitats. Column height gives total grams of carbon per square meter per year, which is the sum of algal and vascular plant productivities. Multiply by 2.2 to approximate grams of organic matter per square meter per year

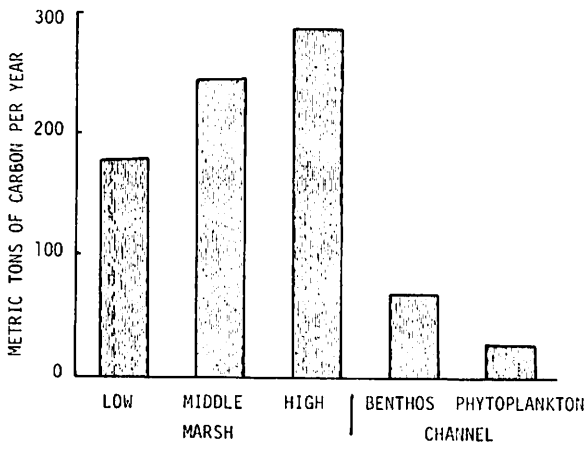


Fig. 2. Contribution of five wetland habitats to the Tijuana Estuary carbon pool (food base). Data are values from Fig. 1 multiplied by areas of each habitat and represent total food production for the wetland ecosystem

In contrast, the succulents provide a rapid release of food throughout large areas of southern California marshes. The combination of a slowly decomposing cordgrass (with high per area productivity) and rapidly decomposing succulents (over large areas) should provide a year-round source of detritus for estuarine consumers.

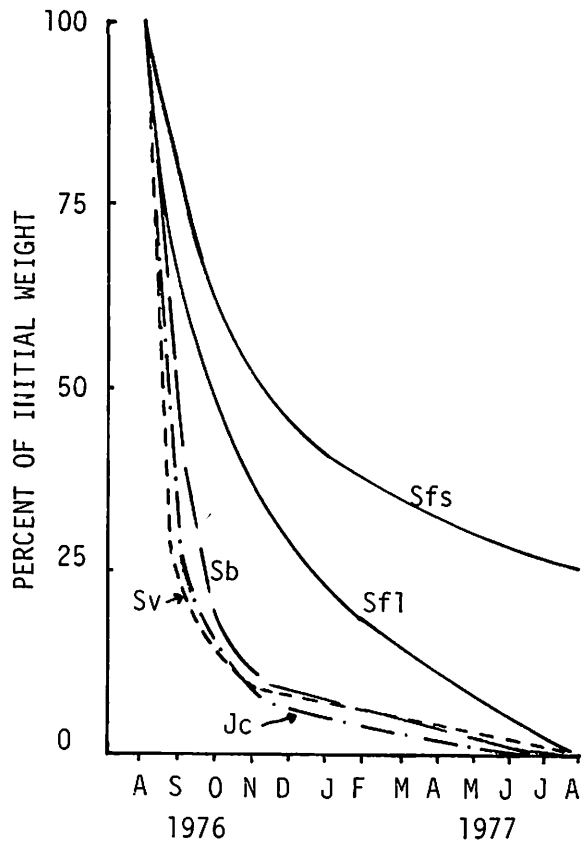


Fig. 3. Comparative decomposition rates for cordgrass (solid lines) and succulents (broken lines). Replicate litter bags were placed in the middle marsh elevations in August 1976; data are proportions of plant biomass remaining in the months which followed. Sfs = *Spartina foliosa* stems; Sfl = *Spartina foliosa* leaves; Sv = *Salicornia virginica*, Sb = *Salicornia bigelovii;* Jc = *Jaumea carnosa* (leaves and stems combined for these three succulents). Data from T. P. Winfield, Research Associate

Salt marsh algal mats

Dense mats, consisting of diatoms, green and bluegreen algae, occur on the intertidal substrates and on the stems of vascular plants throughout the Tijuana Estuary. Unlike eastern marshes, where tall growth of cordgrass seems to limit algal growth, our algal mats are highly productive and equal or exceed the productivity of the vascular plants (Fig. 1). In the lower marsh area, projecting data from nine months study to a year's base, algal mats are slightly lower than cordgrass productivity. In the upper elevations, however, algal productivity equals or exceeds that of the vascular plants. Again, this contrast with eastern wetlands is important to the food chain, since algae are generally edible,

TABLE 1

Net daily exchange of materials at Site A during 1977. All values are in kg. Negative values indicate net export; positive values indicate net import.

Date	NO_2–N	NO_3–N	NH_3–N	POC	PON
5/13/77	–0.03	–21.13	–19.83	– 63.6	– 5.76
5/17/77	–3.42	1.38	8.51	–116.06	–20.67
6/2/77	–0.22	– 0.58	–34.32	—	—
6/16/77	–1.46	–11.59	–25.15	– 75.41	–11.22
6/28/77	–0.571	– 1.12	0.43	0.62	– 2.77
7/14/77	—	—	—	– 51.28	–18.41
7/28/77	0.0	0.0	– 0.294	– 60.54	– 5.18
8/11/77	–0.121	– 0.732	– 7.03	54.06	10.47
8/25/77	–0.4	0.38	– 3.90	– 18.61	– 2.0
9/16/77	–1.49	– 1.43	–12.51	–122.44	–23.87
10/7/77	0.68	– 3.09	–15.12	205.73	46.55
10/28/77	–6.67	3.96	0.0	–249.92	–43.08
11/4/77	1.15	– 0.038	– 0.974	34.98	5.56

TABLE 2

Net daily exchange of materials at Site B during 1977. All values are in kg. Negative values indicate net export from channel; positive values indicate net import.

Date	NO_2–N	NO_3–N	NH_3–N	POC	PON
5/3/77	–0.22	17.85	– 1.91	—	—
5/17/77	0.41	–0.347	3.19	23.45	4.29
6/2/77	–1.03	–0.38	–15.49	–28.26	– 5.07
6/16/77	–0.457	–1.04	–11.11	–54.96	– 4.8
6/28/77	–0.256	–1.08	– 3.27	–92.38	– 6.59
7/14/77	—	—	—	–83.68	– 6.41
7/28/77	0.225	–0.384	– 2.12	–62.03	– 9.22
8/11/77	0.396	0.155	– 3.87	–57.99	–10.09
8/25/77	0.322	0.177	– 0.20	43.14	2.5
9/16/77	–2.64	0.006	–13.03	–49.06	– 9.19
10/7/77	–0.02	27.9	– 4.87	72.93	6.2

and larger proportions of the standing crop are probably grazed directly.

Channel phytoplankton and benthos

In comparison with the intertidal salt marshes, plant productivity in the channels is quite low (Fig. 1-2). The producers here are principally diatoms, with bluegreen algae also present on intertidal mud flats. With an abundance of shellfish consumers present in

the channels, and with good tidal flushing, it is not surprising that algal populations fail to build up to nuisance conditions. Their lower productivity still contributes significantly to the food chain, but calculations of filtering and growth rates of the infauna suggest that the salt marsh detritus is needed to support the high-density shellfish populations. Study of the utility of detritus to benthic consumers is in progress.

Movement of materials

The question of whether Tijuana Estuary is a source or consumer of food has been approached by measuring the movement of dissolved and particulate materials in several major channels in the estuary. Tables 1 and 2 indicate the net exchange of dissolved inorganic nitrogen and particulate organic nitrogen and carbon at two sites draining the upper (Site A) and lower (Site B) marsh areas.

The results indicate a net export of dissolved and particulate matter on the majority of sample dates. Additional work in progress will determine the net movement of dissolved organic nitrogen and carbon from the estuary.

OPENING OF COASTAL LAGOONS BY SAND FLUIDIZATION

Project Leaders: Douglas L. Inman and C. E. Nordstrom

Numerous lagoons occurring along the California coastline do not maintain open inlets to the sea at all times. Closure of the inlets results when tidal currents are insufficient to keep the inlet channel open in the presence of continual littoral transport. Loss of exchange with the open ocean causes stagnation of the lagoon waters and serious degradation of their quality. The principal objective of this project is to apply the technique of duct-flow sand fluidization to the problem of opening and maintaining lagoon inlet channels. A demonstration experiment of the sand fluidization technique was carried out at Los Penasquitos Lagoon in San Diego County by fluidizing a channel across the sand plug obstructing the lagoon inlet.

The principal effort on this project during the past year was two-fold in nature: 1) study of the Penasquitos Lagoon inlet, and 2) development and testing of a duct-flow fluidization system for use in lagoon inlets. Study of the Penasquitos inlet channel was necessary in order to understand the dynamics of a functioning inlet channel and the mechanics of inlet closure. Results of this study provided information for the design of a prototype duct-flow fluidization system. After the lagoon closed, the fluidization system was used to create a new channel and to drain stagnant water from the lagoon.

Penasquitos inlet channel studies

Starting in September 1976, the inlet channel at Penasquitos Lagoon was closely studied by weekly inspections and periodic surveys. Each weekly site visit consisted of plotting the inlet channel position, noting various parameters such as channel width and depth, current speed and then documenting the channel configuration with a series of photographs. In addition, surveys were made periodically to provide detailed data concerning the cross-sectional area of the inlet channel and height of the sand sill. Comparisons between surveys also indicated changes in the volume of sand in the study area at the mouth of the lagoon.

Results of this monitoring program indicated that the inlet channel was quite dynamic with respect to its size and configuration. The lagoon inlet channel frequently changed positions and cross-sectional area in response to sand transport by waves at the mouth of the channel. However, it was found that the channel readjusted itself to an equilibrium position along the revetment wall at the north edge of the study site. The confining effect of the revetment resulted in the scouring of a deep channel at that point, which continued west under the highway bridge. This configuration of the inlet channel often persisted for several months under normal wave conditions.

Large ocean waves often produced an increase of longshore transport which would abruptly alter the lagoon inlet channel. This occurred twice during the past year, causing closure of the lagoon each time. On 15 November 1976, large waves during neap tides filled the inlet channel and closed off the lagoon. Over 2200 cubic meters of sand were deposited in the inlet area in a short period, building up the barrier sill and stopping tidal flow. However, tidal exchange was re-established on 21 November 1976, when spring tides overtopped the sill and tidal currents cut a new channel.

On 21 February 1977, the inlet channel again closed when high waves were coincident with neap tides. This closure was also abrupt with rapid building of the sill and overtopping by high waves which caused the deposition of an overwash fan on the lagoon side of the sill. Surveys after the closure indicate deposition of over 4700 cubic meters of sand in the mouth of the lagoon. The inlet remained closed following this incident until reopened by the fluidized channel.

Sand fluidization experiment

The major effort on this project during the past year was to design and construct a portable sand fluidization system suitable for opening lagoon inlet channels. Using information obtained from study of the Penasquitos Lagoon inlet, a system was designed to cut a new channel across the overwash fan.

The design of the fluidizing pipe used in this study 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 difference equations, predicting pressures, velocities and jet discharges at all points along the pipe. Input conditions were determined from pressure: flow rate curves of the various pumps under consideration. The difference equations were then solved numerically on a digital computer for various pipe diameters, jet diameters, and pipe lengths. The optimum configuration was then selected using the following criteria: 1) jet discharge along the entire pipe should be nearly uniform; 2) the pipe should be as long as possible without the individual jet discharges becoming too small; 3) pump operating conditions should be within the normal operating range. The final configuration chosen was a 100 m long, 10 cm (4 in) diameter filament-wound glass fluidizing pipe with 0.145 cm diameter jets angled at 45° with a spacing of 6.25 cm. Water was supplied to the pipe from a 6 in Peabody Barnes trash pump operating at a flow rate of 50 l/sec (792 gpm) with a discharge pressure of 2.86×10^6 dynes/cm^2 (42 psi).

Unfortunately, the fluidizing pipe was never used in its design configuration due to a mismatching in transport capabilities between the fluidizing pipe and the crater-sink dredge pump. Instead, the pipe was shortened to 49 m and powered by a 4 in trash pump operating at a flow rate of 33 l/sec (520 gpm) and a discharge pressure of 3.85×10^6 dynes/cm^2 (55 psi). Individual pipe sections were coupled with victualic fittings to allow quick assembly of the entire fluidizer. The fluidizer was supported at 10 ft intervals by a series of 2 in by 10 ft long steel pipes jetted vertically into the sand alongside the pipe. Once assembled, the system functioned as shown in Fig. 4.

Starting at the lagoon, the fluidizing pipe was assembled along the intended path of the channel to be cut, and water from the lagoon was pumped through the pipe to fluidize the first section. The fluidized sand was removed from one end of the channel by the dredge pump and discharged away from the channel using the crater sink concept of Inman and Harris, 1970. After completion of the first sections of channel, the fluidizing pipe was removed and reassembled for the next length of channel. The pumps were positioned and the discharge line relocated to form a new spoil pile before the next section of channel was fluidized. This procedure was repeated for each 40 m section in order to complete the entire 210 m channel.

A major problem encountered during the channel cutting operations was the presence of extensive cobble deposits very near to the sand surface. This situation had not been anticipated, since previous studies of the area had indicated the cobbles were buried to depths of mean sea level and below. The necessity of fluidizing a channel through cobble-ladened sand greatly slowed operations. Under cobble-free conditions, the system was expected to move in excess of 100 cubic meters per hour. Instead, the best transport rate achieved by the system was approximately 30 cubic meters per hour, cutting a 1.5 m deep, 3.7 m wide, 40 m long channel in 3.5 hours.

The Penasquitos inlet channel was fluidized in five sections which required about four hours for each relocation of the system. Depth of the channel was determined in relation to the mean sea level (MSL) datum, so

*J. A. Bailard and D. L. Inman, Analytical model of duct-flow fluidization, Proceedings of the Symposium on Modeling Techniques, ASCE/San Francisco, California, 3-5 September 1975, pp. 1402-1421.

that the rim to bottom distance varied over the length of the channel.

At the time of the fluidization experiment the lagoon water level was about 1.0 meter above MSL and on 2 May 1977, when the last section of channel was completed, sea level was 0.6 m below MSL at low tide. This 1.6 m difference in water level caused stagnant water in the lagoon to drain for an eight-hour period until the fluidized channel was filled with sand on the incoming tide (Fig. 5).

Conclusions

Since the principal accomplishment of this project during the past year has been the development and testing of the sand fluidization system, it is appropriate to compare this technique to other procedures for opening coastal lagoons. Penasquitos Lagoon has been opened at other times by hand-digging a trench across the barrier sill to drainage from the lagoon and by mechanically excavating a new inlet channel with a bulldozer. These methods for opening the lagoon differ greatly in approach to the problem and probably represent the opposite extremes of efficiency in operation.

Hand digging a small trench across the barrier sill has been done at times when the lagoon had a high water level and the distance from lagoon to ocean was minimal. The concept is to make a small trench to start flow from the lagoon into the ocean which will then scour itself to sufficient cross-sectional area to form a new inlet. This procedure requires a large labor force in order to dig a trench of suitable size in a reasonable length of time. Usually, this has been done with volunteer labor provided by concerned citizens willing to undertake a strenuous project. Considering the labor-intensive nature of this procedure, it is not economically competitive with any mechanical method. Also,

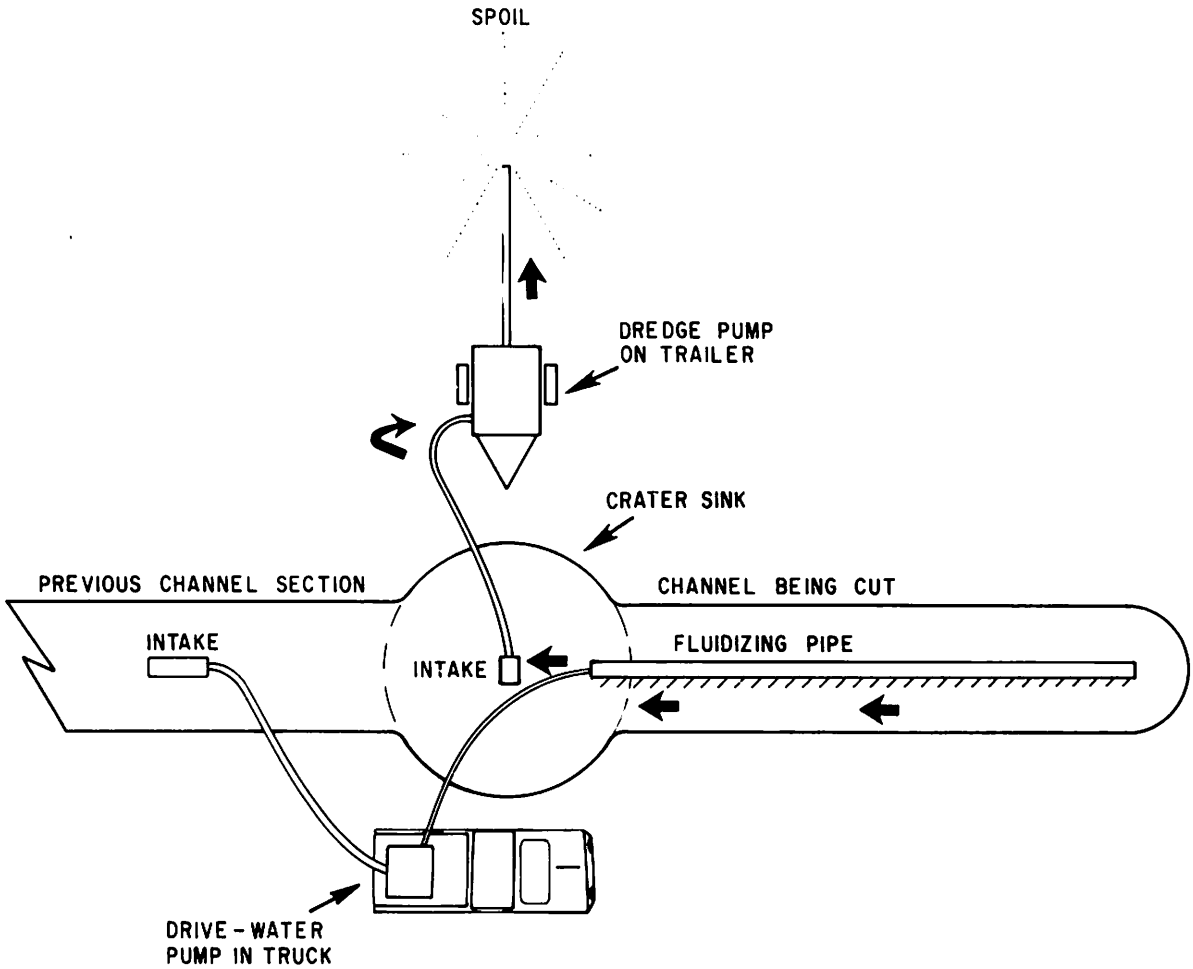


Fig. 4. Schematic diagram of portable sand fluidization system used to open Penasquitos Lagoon

Fig. 5. Fluidized inlet channel at Penasquitos Lagoon with lagoon draining into ocean, 2 May 1977

the success of this procedure has been very limited since the small trench does not scour to a sufficient depth and cross-sectional area to remain open.

An alternative approach that has met with some success is to mechanically excavate a new inlet channel using heavy-duty construction equipment. This has been done at various times using bulldozers, backhoes, and other excavating equipment to remove sand from the inlet area. The most recent effort of this type was in June, 1977, when the lagoon was opened using two small bulldozers. These two machines worked for 12 hours excavating a channel 6 m (20 ft) wide, 1.8 m (6 ft) deep, and 76 m (250 ft) long, moving sand at a rate of 68 m^3/hr (89 yds^3/hr). Excavating of the channel was done seaward of the lagoon leaving a small plug to hold water from the excavation. The channel was formed by the bulldozer pushing sand from side to side while gradually lengthening it toward the sea. Once complete, the sand plug was broken at a low tide level so that the draining lagoon water scours the channel to a larger cross-sectional area. Opening of Penasquitos Lagoon by excavation has had variable success with some channels remaining open for long periods while others closed rapidly. The excavated channel in June, 1977, remained open for two days while the lagoon drained.

The fluidization system as tested at Penasquitos Lagoon appears to be intermediary between the other methods in efficiency. Under optimal conditions at Penasquitos Lagoon with a three-man team operating the fluidizing system, it could move about 30 cubic meters of sand per hour with a few cobble. If the number of cobble increased, the transport capacity of the fluidizing pipe was significantly reduced and the operations required much more time. However, previous use of the fluidizing technique in pure sand with no cobbles indicates that the system could transport up to 100 cubic meters per hour (Harris, *et al.* 1976).* Hand digging a trench is extremely slow and tedious, so that as a practical procedure it cannot be compared to any mechanical method of opening the lagoon. As stated above, the bulldozers could move sand at a rate of 68 cubic meters per hour or over twice as fast as the fluidizing system, but this is offset by several disadvantages, including the cost of the heavy equipment, the necessity of skilled operators, and inability of the machines to operate in water.

The results of the prototype test of the fluidization system at Penasquitos Lagoon indicate that the system can be used to open coastal lagoons where the inlet channel is blocked by a sand barrier sill. When the barrier sill is composed of cobbles, or cobbles mixed with sand, the fluidization system rapidly loses its efficiency and becomes ineffective in moving only cobbles. In pure sand the fluidization system is probably more versatile and efficient than heavy equipment for excavating lagoon inlet channels, but the presence of cobbles at Penasquitos Lagoon significantly reduced the capability of the system to less than that of the bulldozers. Thus, under suitable conditions, the fluidization system could be used to open coastal lagoon inlets more efficiently than any of the other presently used procedures.

*R. W. Harris, 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 Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi.

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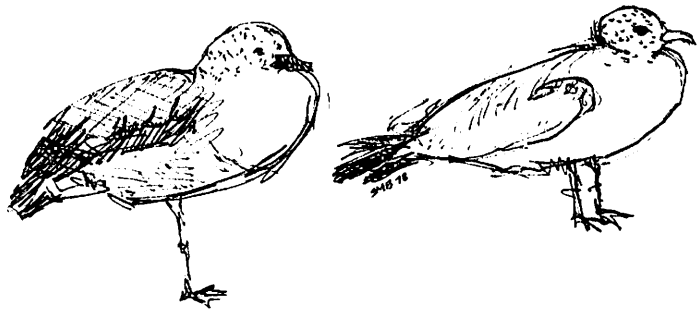
Cooperating Organizations

California Department of Parks and Recreation, Sacramento, California

Institute of Marine Resources, University of California, San Diego, California

University of Massachusetts, Amherst, Massachusetts

U.S. Navy



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

Arcata
R/MR-1

John D. DeMartini

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 and Mr. Burgess Heacox 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 were performed during the summer of 1977. Macrohabitats vary from sand to bedrock. Numerous microhabitats occur, especially in rocky areas, accommodating high species diversity. The biotic assemblages of the two parks are representative of the Sonoma and Mendocino County coasts.

Development of interpretive materials

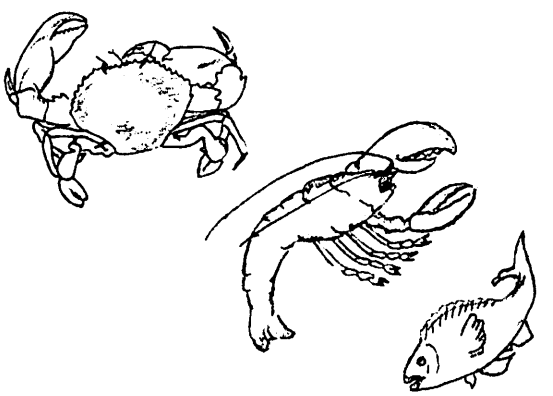
It appears that the initially developed interpretive modes will be presented to audiences of divers and non-divers. Numerous photographs of common marine organisms have been taken and will be incorporated into a variety of displays to be developed on various aspects of marine biology.

Ranger-naturalist workshops

The first of these was organized during the summer at Russian Gulch State Park near Mendocino and was attended by Departmental ranger-naturalists and interpretive specialists from around the state. The workshop lasted four days and proved a success. It included diving, snorkeling, intertidal activities and presentations using the photographs taken during the summer. The next workshop will probably be held during the summer of 1978.

Cooperating organizations

California Department of Parks and Recreation, Sacramento, California



Management of Beach and Dune Vegetation

Michael G. Barbour

Our objective has continued to be a search for inexpensive ways to propagate native plants as stabilizers of beach and dune areas. We wish to find a substitute for European beach grass, *Ammophila arenaria*, which has been widely planted for erosion control but has the negative traits of crowding out the native flora and fauna and grossly altering natural landforms.

Field trials were continued in 1976–77. A series of plots had been erected at North Beach which excluded human traffic; the intent was for us to monitor the rate and magnitude of vegetation recovery. Vandals disturbed the exclosures and plots, and the experiment was discontinued. Culms of dune grass *(Elymus mollis)* and seedlings of beach-bur *(Ambrosia chamissonis)* and sand-verbena *(Abronia latifolia)* were planted to field plots, but the second drought year in a row produced excessive mortality, so results were inconclusive. These failures imply, however, that successful large-scale plantings will be more labor-intensive and expensive than we had first thought necessary.

We now realize that stabilization of large areas of sand with native species must be a more expensive, labor-intensive effort than anticipated. Success in this will require a high density of culms (30+/m^2) to be planted; a supplement of peat moss and fertilizer around each culm; additional watering in the several weeks after planting if rainfall does not keep the sand moist; and possibly the erection of sand fences at least the first year to slow sand movement until the plants become established. In addition, the cuttings of *Ambrosia* require dusting with a rooting hormone and time in a nursery for roots to form prior to field transplanting; and the seeds of some species require pretreatment or rather precise sowing depth for optimal germination. All of these factors would increase the cost of a large project. The superiority of the introduced *Ammophila* over the natives parallels conclusions reached by agronomists cultivating rice and corn in non-indigenous areas. [Peter R. Jennings and James H. Cock, Center of origin of crops and their productivity, *Economic Botany*, **31** (1), 51–55 (1977)].

Other field experiments were more successful. A grid of 50 small salt traps (Fig. 1) was placed in beach vegetation and salt

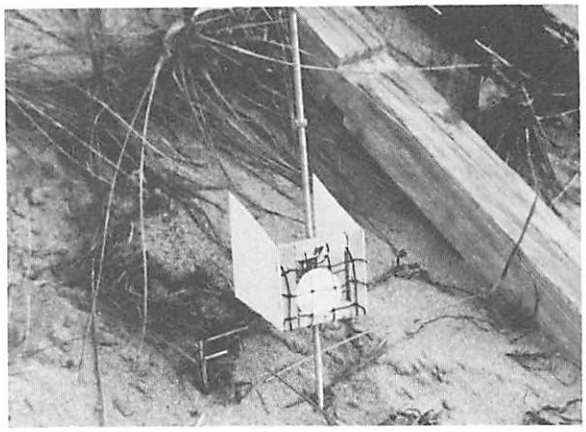


Fig. 1. One of the salt traps erected on the beach. A circular piece of filter paper, held in place by mesh over a wooden frame, traps salt spray. The 10 cm square frame is free to turn on a shaft, and wind vanes along the side orient the trap into the wind

measured weekly during the period of most active plant growth, January–May. A surprisingly steep gradient of salt spray was noted, from the leading edge of vegetation back to the foredune, and the distribution of several species correlated with that salt spray gradient. The distribution of these beach species also agreed with their tolerance to salt spray, as revealed by growth chamber studies last year. Salt spray was also measured further inland, in dune scrub; and nine dune species were treated with salt spray in a greenhouse experiment. The zonation of these dune species, with respect to degree of protection from onshore winds carrying salt spray, correlated well with their tolerance of salt spray. These results imply that transplant species for stabilization must be chosen carefully and matched to the degree of exposure of the site.

Comparison of photosynthetic rates, root systems

Beginning in January, the photosynthetic rates of *Ammophila* and *Elymus* were measured in the field every 2–4 weeks using a portable apparatus that supplied radioactive

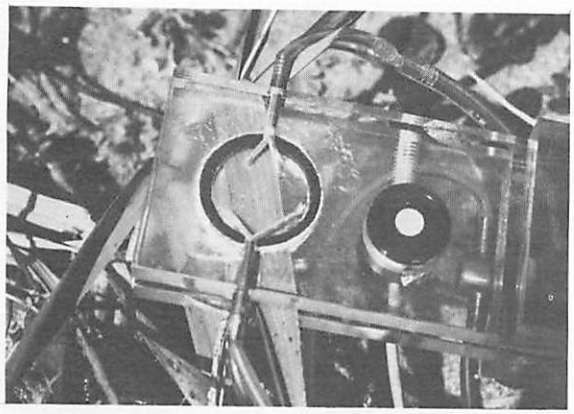


Fig. 2. The chamber into which radioactive carbon dioxide is allowed to flow. As the leaf photosynthesizes, its tissue becomes radioactive, and the level of radiation is determined on the Davis campus

carbon dioxide to a small chamber which was clamped onto leaves for 10 seconds (Fig. 2). The leaves were then taken back to Davis for determination of radiation level. Results to date indicate that *Ammophila* may have a higher photosynthetic rate than *Elymus* during the greater part of the year, especially in the wetter seasons; this advantage may explain its aggressive ability to crowd out *Elymus* and other natives. *Ammophila* may also suffer less from drought because of a more extensive/intensive root system, capable of tapping more soil moisture, and a leaf rolling habit, which may reduce transpiration. Figure 3 shows the length of roots of both grasses recovered at foot-intervals of depth: *Ammophila* had about twice the density of roots at every depth as *Elymus*.

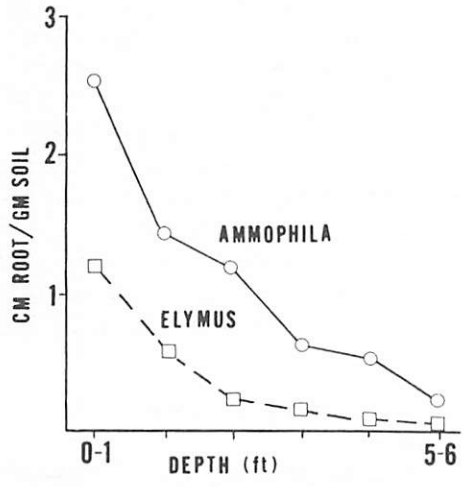


Fig. 3. The length of roots of two beach grasses per gram dry weight of soil. The soil was collected in 1-ft increments of depth, by inserting a tube into the soil

Propagation experiments in the greenhouse showed the importance of organic matter and nitrogen on plant growth. Beach soils contain only about 0.02 per cent nitrogen and 1 per cent organic matter, compared to dune topsoils further inland which contain 10 times those amounts. Beach plants tolerate such a low nitrogen level, yet do not require it and they grow dramatically faster with even modest nitrogen augmentation. The species shown in Fig. 4 were grown for 2-4 months

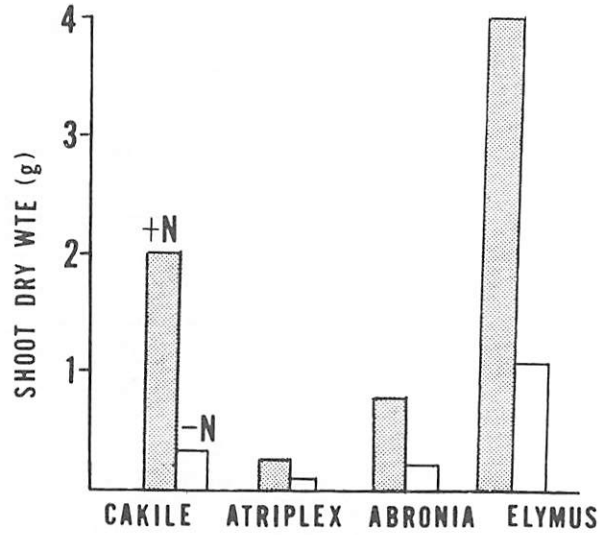


Fig. 4. Shoot weight of four beach species after growing 2-4 months in two treatments: watered twice during that period with complete Hoagland's solution (including 243 ppm N; shaded bars; +N), and watered twice with Hoagland's solution lacking nitrogen (open bars; -N)

in sterile sand; they were watered with distilled water, and twice with Hoagland's nutrient solution. A control group were watered with complete solution, including 243 ppm N, and a treatment group with solution lacking only nitrogen. *Elymus* and *Cakile* showed a fourfold increase in growth due to nitrogen; *Abronia* and *Atriplex* showed a doubling. Organic matter also improves soil moisture retention, in addition to supplying nitrogen. Experiments with different forms of nitrogen (nitrate vs. ammonium) are continuing.

Germination trials with *Abronia* and *Ambrosia*

We had previously shown that cuttings of *Ambrosia* could be readily induced to root if dusted with rooting hormone; experiments

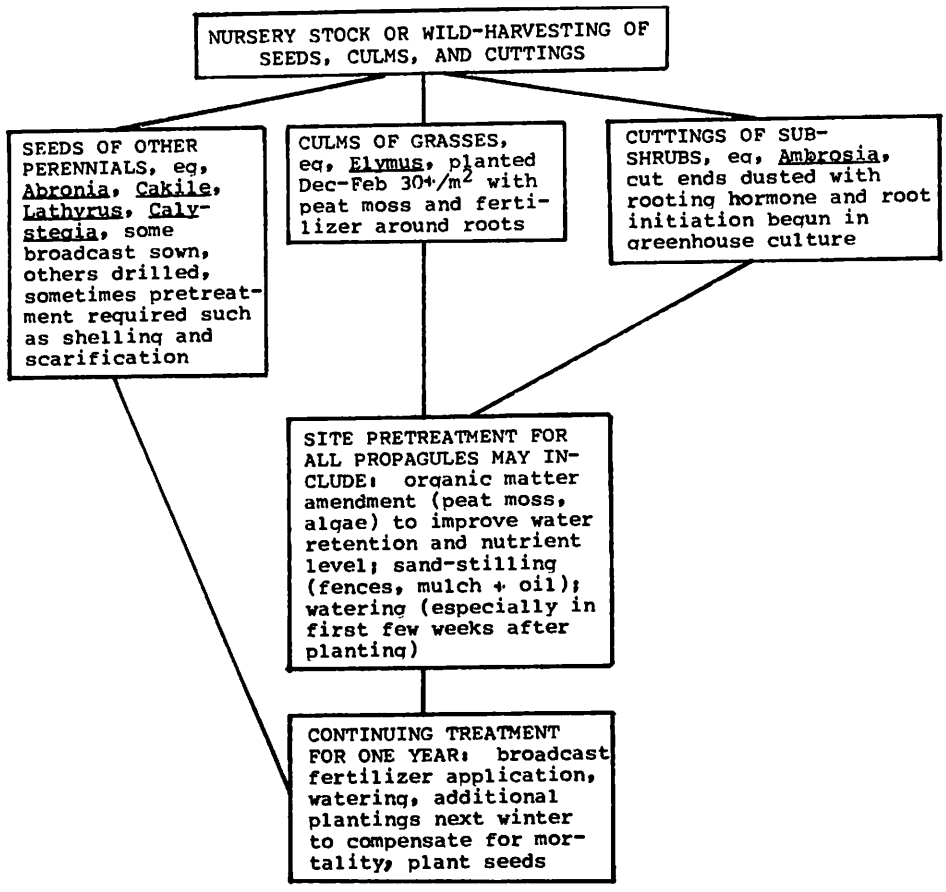


Fig. 5. A generalized flow chart for stabilization of beach and dune with native plants. Vegetative plantings are recommended prior to seed sowing, and replantings to compensate for mortality may be necessary for several years, though only two years are shown

this year with *Abronia* showed that it could not be vegetatively propagated in this way. Consequently, *Abronia* must be sown by seed. Germination trials this year showed that optimum germination results when seeds are removed from the surrounding fruit (anthocarp) and sown 1 cm deep in wet sand. Germination rate in four weeks is 40-50 per cent. *Ambrosia*, on the other hand, gives only about 10 per cent germination when the achenes are similarly planted; consequently it is best propagated by cuttings. Seeds of other species require shelling *(Cakile)*, scarification *(Lathyrus)*, or surface sowing *(Camissonia, Baccharis, Haplopappus)*. Seedlings will do best if the site is first somewhat stabilized by dune grass and beach-bur. A flow chart (Fig. 5) for large-scale plantings shows that seeds are added a second year, following the introduction of *Elymus* culms and *Ambrosia* cuttings the first year.

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Holton, B., Jr., Some aspects of the nitrogen cycle on the beach and dunes of Point Reyes, California. Thesis, 1977.

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Cooperating Organizations

United States Park Service, through Point Reyes National Seashore

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

California Academy
of Sciences
R/CZ-28

Welton L. Lee

The purpose of this project has been to develop a central information source on the invertebrate fauna of San Francisco Bay, to maintain this information in a reference collection, bibliography, and collection repository, and to enhance and standardize research on invertebrate fauna by the production of identification manuals. These manuals represent an entirely new approach in invertebrate taxonomy, and are designed to be used by persons with a wide variety of needs and background in biology.

This review constitutes the final report on the UC Sea Grant portion of the San Francisco Bay Project. As such, it will summarize the activities of the project during the two years of Sea Grant funding.

Previous studies

A treatise by Frederic Nichols in 1973* pointed out the serious shortcomings of nearly all of the various research studies, surveys, and environmental impact reviews which have been made on San Francisco Bay and the Bay-Delta. Various causes were found for these inadequacies, but foremost among them were the failure to retain specimens for taxonomic documentation and future study, and the great lack of accurate, up-to-date and easy-to-use identification guides to the various invertebrate groups. With the decline of interest in taxonomic study and collection maintenance at the university level, the Department of Invertebrate Zoology of the California Academy of Sciences decided that it could provide a unique service to the Bay area by developing services that would compensate for the above-mentioned inadequacies.

Objectives of present survey

After two years of operations under private funding, in which most of the groundwork and planning for the project were completed, the Department of Invertebrate Zoology, with the cooperation of San Francisco State University, applied to the UC Sea Grant Program for funding to move the project into full operation. Its primary objectives were:

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

Results

With the completion of Sea Grant funding, it is possible to report that these objectives have been largely met, and in some cases even exceeded. The reference collection has been essentially completed for some groups, in particular the bivalve molluscs, acmaeid gastropods, and spionid polychaetes. Workers interested in examining these groups will find a large, fully identified series, with full documentation. Specimens from all portions of the Bay and Delta are included. Other groups continue to be processed at the present time, and certain collections will be substantially refined with the completion of manuals for those groups.

The bibliography has proven to be a valuable reference tool for anyone interested in research on San Francisco Bay. It has

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

grown considerably in the past two years; we estimate that more than half of the appropriate references have been incorporated into the bibliography at this time. Funding is being sought, and some has already been received, to complete this important work. The cross-referencing of items by author, subject, location and taxon has been accomplished for many of the references, and a library location code has been provided for rapid access to the original article.

The repository also has grown tremendously during the past two years, the Department now has the most complete collection of San Francisco Bay and Delta invertebrate fauna available anywhere. We have been able to obtain virtually every major collection of Bay fauna taken by individuals and agencies. Some examples include: *USS Albatross* collections (early 1900's), Dr. Frank Filice collections from the University of San Francisco (the first quantitative studies ever made of Bay fauna), the University of California research collection, and the U.S. Army Corps of Engineers Dredge Disposal Study. In addition, a large number of research, baseline, monitoring, and environmental impact assessment collections have been deposited here. We anticipate that more collections will be deposited in the future.

Recognition of the value of these collections and the need for their preservation is reflected in the requirement of the State Water Resources Control Board that collections made under their auspices must be retained, curated and properly archived. This recognition of the services that the Academy and other similar institutions can provide is one of the most rewarding aspects of the project. The use of San Francisco Bay Project materials has already dramatically indicated the beneficial effects and influence which the project has had relative to research standards for San Francisco Bay.

The identification manual series has been a major achievement of the project. This series provides a comprehensive identification source for persons of all levels of taxonomic expertise. The concept incorporates the best aspects of previous identification attempts, and provides ready access to the primary literature through its illustrated glossary, list of synonyms, and extensive bibliography. At present, the manual for the spionid polychaetes is about to be published, and will soon be followed by a manual for the acmaeid gastropods. In addition, a number of researchers have pledged contributions to the series.

Future plans

One of the most important aspects of the Sea Grant philosophy is the desire to provide "start-up" funds for projects, which will be able to continue after that funding has ended. For the San Francisco Bay Project, this goal has certainly been achieved. In addition to the bibliographic funding mentioned above, work on the reference collection continues through departmental involvement and volunteer assistance, and a major grant proposal is currently being reviewed by the Environmental Protection Agency for funding of several aspects of the project. The National Science Foundation has renewed funding for the polychaete manuals for another two years, with Ms. Barbara Weitbrecht, a Sea Grant trainee this past year, as Project Leader. Ms. Barbara Bowman, the other trainee, will complete her work on two sponge manuals.

Funding was obtained last year from private sources to make a survey and collection of fauna from the south end of San Francisco Bay, an area poorly represented in our collections. In addition, other private funds were obtained to be used as matching funds on the National Science Foundation Grant. Several large collections due to be deposited in the coming months will come with adequate funding for the curation and maintenance of these collections.

The manual series will continue as well. Mr. David Lindberg, the author of the acmaeid manual, has several more manuals in various stages of completion. Dr. Vida Kenk, a malacologist from San Jose State University, has begun work on a manual for the mytilid bivalves.

A final indication of the continuation of the project after the completion of the Sea Grant funding is the plan for a "permanent home" within the Department for all Bay Project-related activities and information. This facility will provide even better access for anyone wishing to study the collections, bibliography or other project materials.

Publications

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Sponge families from the northeastern Pacific Ocean (Porifera). In preparation.

Idem, Invertebrates of the San Francisco Bay Estuary System. Identification Manuals. Porifera. In preparation.

Kenk, V.C., Invertebrates of the San Francisco Bay Estuary System. Identification Manuals. Family Mytilidae (Mollusca, Bivalvia). In preparation.

Lee, W.L., The San Francisco Bay Project: a new approach to using systematics, *Association of Systematics Collections Newsletter,* 5(2), 16-18 (1977).

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Idem, Invertebrates of the San Francisco Bay Estuary System. Identification Manuals. Family Alviniidae (Mollusca, Gastropoda). In preparation.

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Weitbrecht, B.E., Invertebrates of the San Francisco Bay Estuary System. Identification Manuals. Families of polychaetes from the northeastern Pacific Ocean (Annelida, Polychaeta). In preparation.

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American Association for the Advancement of Science, Pacific Division; 58th Annual Meeting, San Francisco, California; 12-16 June 1977.

Lee, W.L., and J.E. Sutton, The San Francisco Bay Project: an integrated information baseline.

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

Lindberg, D. R., Cenozoic phylogeny and zoogeography of the Acmaeidae in the eastern Pacific.

Idem, Marine plant limpets in the northern Pacific: Neogene phylogeny and zoogeography.

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

Cooperating organizations

Association of Bay Area Governments, Oakland, California

California State Department of Parks and Beaches, Sacramento, California

Hearst Foundation, San Francisco, California

Lawrence Radiation Laboratory, University of California, Berkeley, California

Leslie Salt Company, Newark, California

National Science Foundation, Washington, D.C.

Pacific Gas and Electric Company, San Ramon, California

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

San Francisco Bay Regional Water Quality Control Board, Oakland, California

South Bay Dischargers Authority, Santa Clara County, California

State Water Resources Control Board, Sacramento, California

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

U.S. Bureau of Reclamation, several branches

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

U.S. Geological Survey, Menlo Park, California

Assessment of the Offshore Commercial Sand and Gravel Potential on the Central California Continental Shelf

Pat Wilde and W. B. N. Barry

The primary objective of this project is to delineate areas of sand and gravel deposits on the central California continental shelf that are potentially useful for commercial production and sale to the building industry.

Sand and gravel comprise the second most important non-petroleum mineral commodity produced in California. In 1973, sand and gravel accounted for a value of $162.3m. or 21 per cent of the value of minerals produced in the state.* The growth of metropolitan areas increases demand for sand and gravel as aggregate. Yet, at the same time, such growth results in conditions that inhibit, and eventually, prevent utilization of many land-based aggregate resources. Operation of a gravel pit is, for example, noisy, dusty, and generally esthetically objectionable. Because of these unpleasant aspects, the expansion of housing and shopping areas as well as zoning restriction will force users of aggregate in urban areas to bring in this commodity from greater and greater distances. This transportation will magnify not only costs but also the already heavy truck traffic. The problem for future planning is, therefore, to provide sufficient aggregate to meet building and other construction needs, and yet, at the same time, avoid the presence of gravel pits in urban areas. In states with coastal areas, a reasonable solution is possible. For example, much of the commercially used sand and gravel in Great Britain comes from offshore deposits in the North Sea. At present, nearly 30 per cent of the aggregate requirements of the Greater London area are met from marine deposits. The dredged material is obtained in the North Sea, transferred to barges and is sized and washed during the journey up the Thames to London. The operations are designed not to interfere in general with the valuable North Sea fishing grounds.

Since offshore deposits have proven of commercial value in Great Britain, and the central California area is growing rapidly, using increasingly large quantities of sand and gravel in the growth process, it seems reasonable to consider the possibilities of locating potentially commercially useful sand and gravel deposits on the central California continental shelf. The identification of such deposits should provide planners with readily accessible and recoverable sources of aggregate to meet the needs of the state in the urban areas about San Francisco and San Jose, without creating a difficult environmental problem. The ecological consequences of their mining may be considered even at this stage.

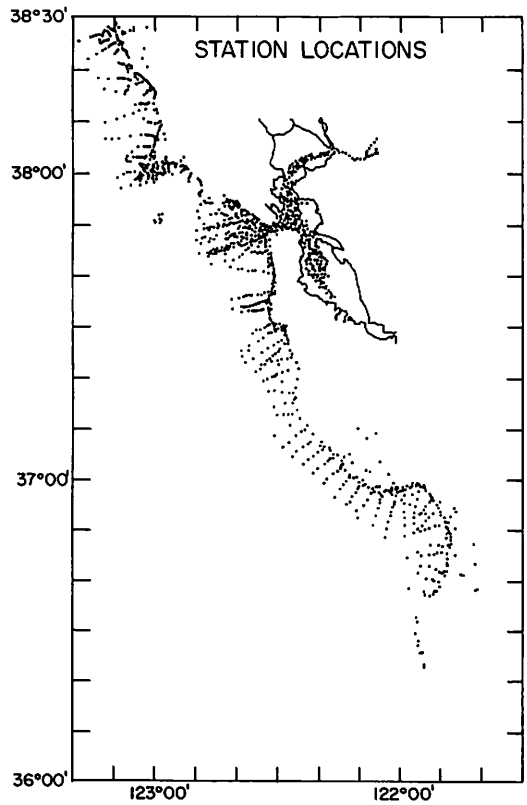


Fig. 1. Computer-generated outline map of the central California coast and San Francisco Bay, showing station locations

*Davis, F.F., and J.R. Evans, Mineral production in California, *California Geology*, **27**, 128-134 (1974).

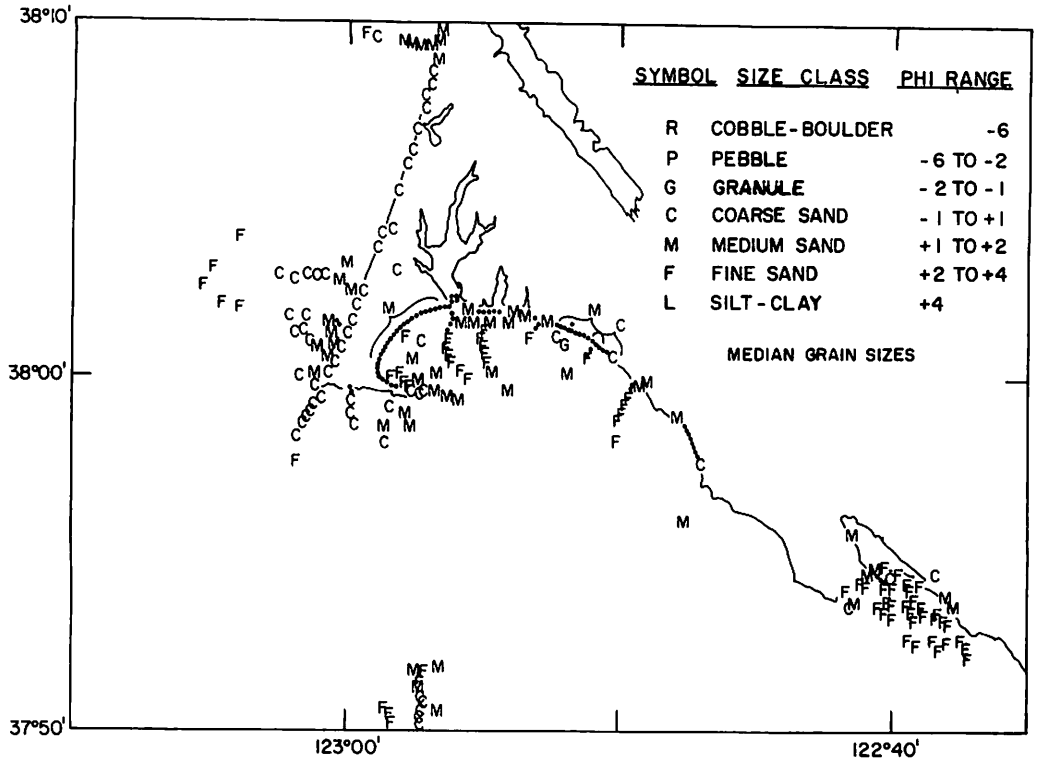


Fig. 2. Computer-generated map with coded grain size distribution data

Extensive collection of samples

The University of California Museum of Paleontology houses a collection of about 3000 samples obtained from the California continental shelf and beach areas north of Point Conception. The samples have been examined critically to obtain both a general description of each as well as to ascertain the presence of any unique mineralogical or biological components. Grain size distribution in each sample has been determined, and the data have been stored in a computer. In addition, for each sample the following information has been stored in the computer: location at which it was taken (that is, its latitude and longitude) as well as its position in relation to the beach, intertidal, or shelf; sampling device used; the exact date and time of sampling; water depth over the sampled site; sediment description; key to any publication of data relevant to sample; and field number of sample.

After these data were stored in the computer, it was programmed to generate an outline map of the central California coastline and that of the San Francisco Bay area. The computer also was programmed to generate the sample location and grain size distribution data (in code) on the computer-generated base maps. A strip atlas of computer-generated maps showing locations at which samples were obtained and the coded grain size distribution data are being generated (see Fig. 1 and 2 for examples). Approximately 200 micro-fiche copies of the atlas are available for general distribution.

Planned future maps will include sorting coefficient information and other pertinent statistical information for each sample, and when appropriately analyzed, will lead to delineation of potentially commercially useful sand deposits on the central California coast. The project is only in its first year, and the analyses of plotted sample data and location of potentially useful deposits remain to be carried out in the future.

Publications

Wilde, P., K. Leslie, W. Niebuhr, and J. Sandusky, *Catalogue of Marine Sediment Samples of the Paleontological Museum*, University of California, 1977 Technical Report microfiche, in press.

Cooperating organizations

California State Lands Commission, Long Beach, California

Lawrence Berkeley Laboratory, University of California, Berkeley, California

Diving Safety Research Project

Glen H. Egstrom

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

The third year of our project saw the following activities:

1. The analysis of the functional performance of 38 models of scuba regulators was completed. This long-term study involved testing five regulators of each model under respiration rates of 6, 15, and 30 breaths per minute at depths of 0, 10, 20, 40 and 60 meters at high and low tank pressures. The results have been used to identify the limitations for regulator use and the need for further refinement of existing regulator systems. Several cooperating manufacturers have used our data in the development of a new generation of scuba regulators.
2. A series of evaluations of the effect of different types of diving equipment on diver mobility were completed. These tests included wet suits, flotation vests, tank and back packs on a series of divers. The results point to a rather dramatic reduction in mobility and raise questions regarding the impact of this type of equipment upon diver training requirements. Ascent rates and buoyancy characteristics of 14 personal flotation devices were also determined.
3. Two studies of the effects of underwater exposure on the rate and efficiency of learning psychomotor skill have been completed. A two-handed coordination task and a "buddy breathing" skill were tested and learning curves developed. The results show that a significantly greater number of learning experiences are required to reach a learning "plateau" than are currently required in most basic student training courses. Suggestions for revision of training procedures to ensure a greater degree of positive reinforcement during the learning of critical skills have been generally accepted by instrumental agencies. Of particular value was the finding, through analysis of video tapes, that many novice "buddy breathers" stop swimming when they are initiating buddy breathing procedures. This practice results in the divers sinking to the bottom of the pool.
4. A comparison of the rules of behavior developed by the four major training agencies as of 1975 has revealed an interesting variation in the instructional approach to a number of training problems. Two of the agencies, Professional Association of Underwater Instructors and National Association of Skin Diving Schools, utilize a rather specific approach with clearly identified rules of behavior. The National Association of Underwater Instructors and YMCA on the other hand provided guidelines with few rigid requirements. This difference in approach was especially obvious in the matter of emergency procedures and some critical skills where, for example, one group would provide step-by-step directions as opposed to an admonition to familiarize with buddy breathing. Considerable progress has been made in the standardization of emergency procedures and in training objectives by these agencies since 1975, and a greater awareness exists for the remaining problem areas.
5. Studies of weight belt ditching procedures and surf entry and exit techniques have been completed. A review of 208 video-taped entry and exit performances was analyzed. An accumulative loss of control was noted in which relatively small problems became magnified into potentially dangerous situations. Inappropriate solutions to small problems apparently increase stress and result in

inappropriate response to a more serious problem. For example, stopping progress through the surf zone to adjust a faceplate can result in being knocked down by a wave. Various problem categories were identified and training suggestions developed.

Weight belt ditching mechanics were studied from which we learned an important lesson: contemporary procedures must take account of the fact that weight belts which are disengaged will *not* drop if the body is more than 30° from the vertical. Therefore, a positive ditching technique must be learned so that the belt will be pulled away from the body.

Presentation of results

These investigations have been well received by the diving community and have generally led to sensitizing the public to the problems experienced in training safe, effective divers. The results have been presented at six international, 19 national and seven local meetings; some of this new information has been incorporated into eight publications to date. The preparation of detailed reports is in progress.

Consulting services have been requested and given to various agencies of the government, research and development groups and private industry.

The work is likely to have a lasting impact, and reports and publications will be forthcoming during the remainder of 1977 through mid-1978. A request for a presentation of project results has been received from the South Pacific Undersea Medical Society for its conference in June in Suva, Fiji, at their expense.

Requests from England and Canada have also been received, but limited funding for these presentations may preclude honoring the invitations.

The project has been a significant success and has stimulated the diving agencies and diving industry to renew their efforts in developing programs to meet identified problems.

Publications

Egstrom, G.H., Industry programs for marine education and manpower, Proceedings of Marine Technology Society – Oceans '77. Los Angeles, California, 1977.

Idem, Sport diving safety, Proceedings of the Third International System Safety Conference, Washington, D.C., 1977.

Idem, U.C.L.A. – Diving safety research, Proceedings of the Eighth International Conference on Underwater Education, San Diego, California, 1976.

Idem, Underwater skill acquisition, *Undersea Biomedical Research*, Vol. 4, No. 1, 1977 (abstract).

Idem, Diving safety research, Proceedings on CNCA Conference, Champaign, Illinois, 1976; in press.

Idem, Diving safety research, Proceedings of the Ninth International Conference on Underwater Education, Miami Beach, Florida, 1977; in press.

Idem, Research for improved diver performance, Proceedings for International Diving Symposium, New Orleans, 1977; in press.

Kise, B., An anthropometric analysis of the restriction in scuba diver mobility. Thesis, University of California, Los Angeles, California, 1977.

Lecture presentations were given to the following organizations:

Association of Diving Contractors Conference, New Orleans, Louisiana

California Advisory Committee on Scientific and Technical Diving, University of California, Los Angeles, California

California Diving Officers Meeting, University of California, Los Angeles, California

Commercial Diving Center, Wilmington, California

Council for National Cooperation in Aquatics, Champaign, Illinois

County of Los Angeles Beach Advisory Committee, Los Angeles, California

Diving Equipment Manufacturers Conference, Miami, Florida

Eastern United Surf Life Saving Club, Auckland, New Zealand

Failure Analysis Conferences, Pajaro Dunes, California; and Tahoe, Nevada

Instructor workshop (NAUI), University of California, Los Angeles, California

International Conferences on Underwater Education, Miami, Florida; and San Diego, California

International Conference, Undersea Medical Society, Toronto, Canada

Los Angeles County Department of Parks and Recreation, Advanced Diver Program, Los Angeles, California

Los Angeles County Sheriffs Training, City of Commerce, California

Marine Technology Society, National Conference, Los Angeles, California

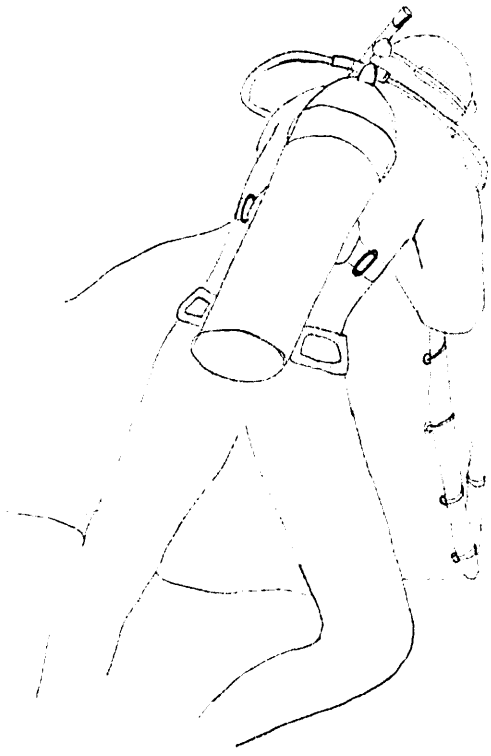
Naval Medical Research Institute, Conference on Standardization of Underwater Performance Measurement, Bethesda, Maryland
NOAA Safety Workshop, Chicago, Illinois
Our World Underwater Conference, Chicago, Illinois
Santa Monica City College, Santa Monica, California
System Safety Society, National Conference, Washington, D.C.
Training review for Los Angeles Police Department – Underwater Recovery Unit, Los Angeles, California
Undersea Medical Society, Washington, D.C.
United States-Japan Diving Technology Panel, informal discussion, Buffalo, New York
World Underwater Congress, Brisbane, Australia

Cooperating organizations

Behavioral Sciences Laboratory, Naval Medical Research Institute, National Naval Medical Center, Bethesda, Maryland
Commercial Diving Center, Wilmington, California
Diving equipment manufacturers:
- AMF Voit, Santa Ana, California
- Aquacraft, San Diego, California
- Dacor Corporation, Chicago, Illinois
- Farallon Industries, Belmont, California
- New England Divers, Los Angeles, California
- O'Neil, Inc., Santa Cruz, California
- Parkway-Poseidon, Perth Amboy, New Jersey
- Scuba Pro, Paramount, California
- Sherwood-Selpac, Santa Ana, California
- Sportsways, Inc., Paramount, California
- Sub Aquatic Systems, Redondo Beach, California
- Techna, Menlo Park, California
- U.S. Divers, Santa Ana, California
- White Stag, Inc., Marina del Rey, California

Leonard Greenstone Company, Los Angeles, California
Los Angeles County Department of Beaches, Los Angeles, California
Los Angeles County Department of Parks and Recreation, Los Angeles, California
National Scuba Training Council:
- NASDS, Long Beach, California
- NAUI, Colton, California
- PADI, Santa Ana, California
- SSI, Denver, Colorado
- YMCA, Key West, Florida

Video Sciences International, Burbank, California



Coastal Governance in California

Berkeley
R/CZ-38

Eugene C. Lee and Stanley Scott

This study covers the legislative history of the 1976 coastal statutes, and reviews the process for appointing the new commissions. It also examines the early phases of the state-local collaborative planning process provided for under the new legislation, which shifted the center of coastal planning activity from the state level to local governments. The latter now have principal responsibility for drafting the local coastal plans, which must be reviewed and approved by the state coastal commission.

Some 70 formal interviews were conducted and transcribed, plus approximately 60 informal ones, including telephone interviews, collecting information on the following: (1) history of the 1976 coastal legislation; (2) views, attitudes and conclusions of selected "carry-over" members of state and regional coastal commissions ("debriefing interviews"); (3) the process of appointing the new coastal commissions under the 1976 legislation; (4) the views and conclusions of observers representing selected interest groups concerned with coastal governance; (5) state-local issues with respect to recreational use of the coast; (6) selected permit decisions that were appealed to the regional and state levels; and (7) the initial experience of city and county coastal planners in implementing the 1976 legislation. (Work on the last two items has been pursued principally under a two-month grant extension to October 31, 1977, and these will be in addition to the 70 formal and 60 informal interviews noted above.)

Library research was done and files collected with special reference to (1) legislative history, and (2) issues of recreational use of the coast. Writing was done on marine and coastal recreation issues, resulting in an 85-page manuscript "Coastal recreation in California: Future directions for local and state policy" prepared by Sea Grant trainee Elizabeth Fuchs, and submitted as her Professional Report in qualifying for the degree Master of City Planning. This text was revised and edited during the summer; after updating, it is anticipated that it will be issued as a Working Paper. Also a 45-page draft manuscript was prepared on the legislative history of the principal coastal bills in 1976. This will be fleshed out into a Working Paper or Research Report on the legislative history, and will also be a chapter in the projected book on coastal governance. Work on this material is continuing under Sea Grant R/CZ-41, Coastal Governance in California, but some preliminary findings can be reported here.

Legislative history

As might be expected of major legislation in a highly controversial area, the coastal bill's history has emerged as a classic case of the working of the legislative process. Ultimately successful, the 1976 legislative effort was a curious blend that combined skilled strategic planning and astute maneuvering with substantial helpings of inexperience and amateurism, bloopers, and cliffhangers.

That the process produced a statute is largely because of some uniquely fortunate circumstances. On several occasions, "the right person was at the right place at the right time." A major factor in the successful compromise was the coastal bill's opponents' fear that failure to enact a reasonably good law might spark a strong initiative effort, like the one in 1972 that won voter approval of Proposition 20. Also, they finally accepted the compromise that passed, partly because of their fear of lacking sufficient votes to stop it.

On the other hand, proponents of coastal conservation were willing to compromise partly because they desperately wanted some kind of coastal legislation before the entire system "self-destructed" at the end of the year under the terms of Proposition 20. Unless they compromised, they might get no law at all. The final break came when key forces favoring a "weak" bill, led by the general contractors, followed closely though perhaps reluctantly by the building trades unions, were instrumental in approving the compromise shortly before its enactment on the eve of legislative adjournment. Other major coastal interests, including the ports,

the utilities, and the petroleum industry, had already obtained the principal concessions they considered essential.

In achieving the win, key actors played some remarkable roles, including the Speaker and several committee chairmen, as well as individual legislators and legislative staff members. Able lobbyists contributed insight and skills in negotiating acceptable compromises. Governor Brown intervened with an effective 11th hour intercession that got the principal bill over the last of its hurdles, his threat to call a special session on coastal legislation providing the clout that pushed the coastal package through.

Coastal zone plans: The principal issues

Under the system of coastal planning and regulation established by the 1976 legislation, the center of action shifted to the local level. There, the coastal cities and counties are responsible for drafting local coastal plans, under guidelines prepared in 1977 by the state commission. (These local activities will be monitored in 1977-78 under Sea Grant Project R/CZ-41.) During this period, and on into 1980, local plans will be developed and reviewed by the regional and state commissions. The local coastal plans and zoning ordinances to implement them are intended to be completed, and certified by the state coastal commission, by 1980 or 1981 at the latest.

Except for a number of pilot projects, this process has now barely begun, but already some emerging conflicts have been emphasized by the new coastal effort. Not surprisingly, recreational uses of the coast and the numerous potential conflicts of interest involved, seem certain to be among the most significant and difficult subjects of coastal planning and policy development. Legitimate interests that can often clash include (1) the need to provide appropriate additional access and recreational uses of the coast, (2) the need to preserve and protect coastal resources against environmental damage from excessive or inappropriate uses, (3) the need to provide financial assistance to localities for recreational resource development, maintenance and management, (4) the need for direct state provision of major resources such as state parks, and (5) the concerns of local communities whose residents fear that congestion and excessive intrusions by "outsiders" lured by new coastal recreational opportunities may have major adverse effects on privacy and the quality of life in their communities.

Reconciling these and other conflicts will take a high level of professional planning activity, weighing the various potential impacts, as well as some statesman-like negotiation among the politicians and policymakers. This will be going on throughout the process of local coastal plan preparation, review and approval.

Aside from coastal recreation uses, and issues of access to the beach, coastal planning will probably have its greatest impact in the rural areas. The future of coastal agriculture is thus a critical problem to be dealt with. How can agricultural lands be preserved, and what feasible alternatives are available when an agricultural use proves uneconomic? Other principal issues include the appropriate protection of wetlands and other resource areas against undue impacts from future growth, and the preservation of scenic quality along the coast.

In this connection, major decisions must be made on the potential impacts of future growth-generating facilities such as highways, water supply and sewage disposal. Decisions on expansion or nonexpansion can do much to determine future development and uses in the coastal zone. Accordingly, along with land-use regulation and public acquisition of property, the control and appropriate limitation of growth-generating facilities will be a major means for coastal plan implementation. The big job ahead is to develop coastal plans that deal with these problems in a way that suitably reconciles the conflicts of interest involved, while achieving the objectives of coastal protection.

Publications

Costonis, J.J., C.J. Berger, and S. Scott, Regulations v. compensation in land use control: A recommended accommodation, a critique, and an interpretation. Published by the Institute of Governmental Studies, University of California, Berkeley, California, 1977.

Scott, S., California needs regional commissions: A reply to Peter Douglas, *Coastal Zone Management Journal*, forthcoming in Vol. 4, No. 3.

Note: The Peter Douglas review (*ibid.*, Vol. 3, No. 2), together with the Scott reply, will be issued and distributed in monograph form by the Institute of Governmental Studies.

Cooperating Organizations

Associated General Contractors, Sacramento, California
Association of Bay Area Governments, Berkeley, California
Audubon Magazine, Sacramento, California
California, Assembly, Assistant to the Speaker, Sacramento, California
California Assembly Committee on Natural Resources, Sacramento, California
California Coastal Alliance, Woodside, California
California Coastal Conservancy, Sacramento, California
California Coastal Task Force, Sacramento, California
California Coastal Zone Conservation Commission, San Francisco, California
California Coastal Zone Conservation Commission, Vice-Chairman, San Francisco, California
California Council for Environmental and Economic Balance, San Francisco, California
California Department of Parks and Recreation, Division of Planning, Sacramento, California
California Department of Parks and Recreation, Division of Statewide Studies, Sacramento, California
California Department of Parks and Recreation, Marin Area Headquarters, Corte Madera, California
California Department of Parks and Recreation, Office of Deputy Director, Sacramento, California
California, Executive Office of the Senate Rules Committee, Sacramento, California
California, Office of the Governor, Appointments Secretary, Sacramento, California
California, Office of Senator A. Beilenson, Sacramento, California
California, Senate Natural Resources Committee, Sacramento, California
California, Senate, Office of President Pro Tem, Sacramento, California
California Senate Select Committee on Land Management Organization, Sacramento, California
California, Senator, Sacramento, California
California State Assembly, Office of the Speaker, Sacramento, California
California State Assembly, Office of Research, Sacramento, California
California State Building and Construction Trades Council of California, Sacramento, California
California State Energy Commission, Sacramento, California
California State Legislative Counsel, Sacramento, California
California, State of, San Francisco Bay Conservation and Development Commission, San Francisco, California
California State Office of Planning and Research, Sacramento, California
California State Parks and Recreation Foundation, Oakland, California
California, University of, San Diego, California
California, University of, Sea Grant, San Francisco County Office, San Francisco, California
Central Coast Regional Commission, Redwood City, California
Central Coast Regional Commission, Salinas, California
City of Hayward, California
City and County of San Francisco, California
Golden Gate National Recreation Area, San Francisco, California
League of California Cities, Sacramento, California
League of Women Voters, Coronado, California
Marin County, Planning Department, San Rafael, California
Monterey, County, Supervisor, Monterey, California
North Central Coast Regional Commission, San Francisco, California
North Coast Regional Commission, Eureka, California
Oakland, City of, Office of Parks and Recreation, Oakland, California
Orange County Evening News, Garden Grove, California
People for a Golden Gate National Recreation Area, San Francisco, California
Planning and Conservation League, Sacramento, California
Pleasant Hill, Councilman, Pleasant Hill, California
Santa Cruz, City of, Department of Recreation, Santa Cruz, California
Santa Cruz, County of, Department of Parks, Open Space and Cultural Services, Santa Cruz, California
Santa Cruz Port District, Santa Cruz, California
Sierra Club, Sacramento, California
Sierra Club, Northern California Representative, Santa Cruz, California
South Coast Regional Commission, Irvine, California
Southern California Edison Co., Rosemead, California
Stinson Village Association, Stinson Beach, California
The Trust for Public Land, San Francisco, California
U.S. Coast Guard, Atlantic Area, New York

Methods for Management of the Cumulative Impacts of Coastal Development

Thomas Dickert

The recently enacted California coastal legislation directs local governments to bring their land use plans in conformance with the policies of the Coastal Act. The research conducted during the year was aimed at developing methods for use by state agencies and local governments in developing coastal zone management programs.

For review purposes, the research undertaken during 1976–77 can be divided into two areas of activity, each intended to provide direct assistance to the California Coastal Commission and to develop methods that could be used also by other states engaged in coastal management. Our involvement with the Coastal Commission dates from shortly after the organization of their planning staff in February 1973. The work has been coordinated with the state commission and respective regional commission planning staffs.

Cumulative impact assessment

The primary activity has been the development of analytical methods for assessing the cumulative impacts of coastal development. The methods were developed within the context of a number of case study areas. These included Half Moon Bay, where previous work conducted during the past two years was expanded by the development of a land use and environmental information system; Big Sur and Orange County, where the work was carried out in cooperation with the California Coastal Commission; and Elkhorn Slough, Monterey County, where research focusing on estuary management was started during the current project year.

The development of methods for cumulative impact assessment has been concentrated in six problem areas: 1) Highway, sewage, and water system requirements of coastal land uses in relation to design capacity and levels of service. Of particular concern is the degree to which traffic congestion generated by residential development may restrict visitor access to the coast; 2) Estuary sedimentation and pollution generated by land use activities occurring in the estuary watershed. Of particular concern is the effect of sediment and other pollutants on fishery, wildlife, and recreation resources of wetlands; 3) Deterioration in the scenic qualities of coastal communities and landscapes through development activities and physical modification of the environment; 4) The socio-economic mix of coastal communities and associated land uses. Of particular concern is the exclusion of low and middle income groups from residing or recreating within coastal communities; 5) Conversion of coastal dependent and coastal specialty croplands into non-agricultural land uses; 6) The intensity and distribution of public access and recreation. Of particular concern are the effects that coastal land use and access patterns have upon the environmental quality of the recreational site and the quality of the recreational experience.

One method for cumulative impact assessment which we have developed to address these problems is a parcel-based land use information system. In contrast with previous work in the development of information systems, this system expands the data base available in the county assessor's record to incorporate a broad range of environmental and land use characteristics such as geological hazards, habitats of rare and endangered species, and agricultural and soils capability. The system is designed to serve a number of functions related to the development and evaluation of local coastal programs: determining the number of parcels with a specific set of resource or land use characteristics; testing the degree of conformance between existing local general plans and the Coastal Act policies; and projecting the number of parcels with characteristics similar to a parcel being considered for a specific development proposal. Determining the number of "similarly situated" parcels is the basic task in estimating the cumulative impact of permitting an equivalent use within a specific jurisdiction.

A feasibility study using a portion of the Half Moon Bay subregion, the Montara-Moss Beach area, has been utilized to develop and test the system. Applications of the system in the case study area have included an analysis of several projects in collaboration with the Coastal Commission.

In conjunction with the development of the parcel-based information system, we conducted reviews of automated information systems either proposed or in operation in other coastal states. We also prepared a summary of the status and content of automated assessor's records for coastal counties in California. The review and analysis of automated systems in 10 other states include an examination of the variables encoded, the geographic attributes of the system (sampling methods and degree of resolution), software and hardware requirements, and the current and future uses of the system.

The survey of the county assessor's offices within California was undertaken to establish the transferability of the system for development of local coastal programs. A major finding of the survey was that most of the coastal counties in California either have most of their data in an automated form or are in the process of automating their records. Thus, the approach developed in the research is transferable and could be utilized by cities and counties for local coastal program preparation.

Case study

A second area of activity has been the initiation of a case study in the Elkhorn Slough watershed, Monterey County, focusing on methods for assessing the cumulative impacts of land uses related to the biological and hydrological conditions within an estuary watershed. This case study is intended to provide a prototype planning and management process that can be used in other estuaries within California and other coastal states. A bibliography of more than 400 citations has been compiled and distributed for review to the many agencies and groups involved in planning for the area. Initial data collection, and definition of hydrological and land use analysis units have been completed, including extensive field work verifying the estuary watershed boundary. The initial work has been used to test and recommend revisions to the management zones proposed by the Coastal Commission.

Publications

Burke, J. E., 1977, Recreation planning in the coastal zone. Analytical techniques, information, and policies. Working Paper No. 128, Institute of Urban and Regional Development.

Dickert, T., Land capability and cumulative impact assessment. Paper presented to the Annual Meeting of the Association of Environmental Professionals, Incline Village, Nevada, 1977.

Dickert, T., E. Metz, and S. McCreary, 1977, A policy-based environmental information system for cumulative impact assessment in coastal planning. Institute of Urban and Regional Development, Berkeley (working draft).

Dickert, T., *et al.*, 1977, Collaborative land use planning for the coastal zone – Volume I: A process for local coastal program development, Monograph No. 27, IMR 76-14, Institute of Urban and Regional Development, Berkeley.

Metz, E., 1976, A brief analytical survey of administrative regulation, growth management, and acquisition techniques applicable to coastal land use, Institute of Urban and Regional Development (working draft).

Cooperating Organizations

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

California Department of Fish and Game, Sacramento, California

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

Monterey County Planning Department, Monterey, California

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

AQUACULTURE

The importance of the commercial culture of marine animals and plants for human use has long been recognized, but so far the success rate of large-scale commercial exploitation has been limited. Sea Grant sponsored researchers are dedicated to bring nearer the day that a major viable aquaculture industry can be established to help meet increasing world demand for protein foods. Their main efforts presently are in the development of mass culturing systems using the American lobster as the experimental animal. Knowledge gained in the husbandry of this valuable species could ultimately also lead to practical mass culture of other species, such as the California spot prawn and the Dungeness crab.

As a result of initial work at UC-Santa Barbara and UC-Santa Cruz to develop base-line information and to understand the kelp forest ecology of the southern and central California coasts, an intercampus kelp bed mariculture and resource management program has been established. Thus, as part of this program, investigators at UC-Santa Cruz are studying a red alga that is of potential economic importance because its cell wall contains carrageenan, a compound with important industrial uses. Also at UC-Santa Cruz, investigations were initiated into the effects of public regulation on California's aquaculture industry.

An unusual line of research pursued at UC-Davis, in which crop plants like barley, tomatoes and wheat are bred to tolerate irrigation with highly saline water, has so far exceeded expectations in its progress toward the goal of making available the waters of the ocean to irrigate arid, sandy coastal soils.

Development of the Science and Technology of Aquaculture

Cadet Hand

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

Brood stock development

A significant impediment to commercially viable lobster farming is control over reproduction. Without it, one cannot ensure a steady supply of seed nor begin selective breeding for truly domesticated stocks. In our experience, the major block in the reproduction of either laboratory-mated or wild-caught inseminated females has been low frequency of egg extrusion. Our approach has been to improve husbandry practices and to examine the effects of various temperatures and photoperiod regimes on extrusion frequency. In addition, we have compared *H. americanus* and *H. gammarus* brood stock. Results have been encouraging but by no means definitive.

Eleven matings were followed by egg extrusion over the past fiscal year. Only two other extrusions, both in 1974, can be documented prior to this. Progress has come chiefly through better husbandry (larger tanks, varied diet, generally moderate temperatures), and in part through the successes with *H. gammarus* females in crosses to *H. americanus* males both at Bodega Marine Laboratory (BML) and San Diego State University (SDSU). Details of the experimental results and brood stock observations are given in a paper to be presented at the next World Mariculture Society Annual Workshop, which will be held in Atlanta in January 1978. Two encouraging results were the relatively short times from mating to hatch (often less than one year compared with one year, but more often two years, in nature) and the lack of marked seasonality in reproductive events.

A total of 20 selected genetic crosses were made among laboratory-held brood stock during the year. Many of these were crosses between European and American lobsters. Hybrids from two crosses were successfully hatched and are being reared for study of growth rates. Almost all brood stock at both BML and SDSU have been electrophoretically typed, and a computer data filing system has been initiated.

In summary, the work on lobster brood stock development has resulted in real progress in the past year, and we are now prepared for even more concentrated effort on remaining problems. Selective breeding of cultured lobsters is indeed under way at BML.

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 should integrate both physical systems and biological results into a form that reflects the status of research as a whole. Techniques of mathematical modeling, optimization theory and simulation have been used to fulfill these requirements.

A mathematical model of the biological, physical and economic aspects of culture has been developed, and this was used to determine optimal culture methods, project culture costs, and direct research. Our approach has been to construct an initial model based on available data and assumptions; to determine the sensitivity of the output (cost) to poorly known or assumed parameter values; and to concentrate experimental effort on improved values of these parameters. As research progressed, the model has become increasingly realistic. In addition to directing research so as to improve 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 different proposed research projects. Optimal control theory was used to determine optimal temperature, container sizes and flow rates in lobster culture. Computer simulation has been employed to project culture costs under different assumed conditions.

Water quality/seawater chemistry

The maintenance of low-particulate, micronutrient and bacterial concentrations in crustacean culture systems has been a key factor in producing high survivorships. Under intensive-culture conditions, nutrient and bacterial concentrations quickly increase resulting in a high biological oxygen demand (B.O.D.) If left unchecked, these concentrations are capable of rapidly depleting the dissolved oxygen available for the culture organisms. The effectiveness of mechanical, biological and ultraviolet filtration as a means of reducing the B.O.D. and improving water quality has been demonstrated through the intensive chemical monitoring of our culture systems.

Biological filtration is still the most effective way of reducing dissolved organics and removing ammonia and nitrite from seawater. As this type of filter relies upon bacteria, it is very sensitive to changing environmental conditions. For example, excessive ammonia concentrations can reduce the nitrification capability of the filter; a severe decrease in dissolved oxygen can turn the filter into a lethal hydrogen sulfide generator. For a biological filter to function properly it must be given an adequate supply of oxygen and nutrients. Only by monitoring the concentrations of organic nitrogen, ammonia, nitrite, nitrate and oxygen entering and leaving the filter can one determine its efficiency.

The use of activated charcoal adsorption to remove dissolved organics has proven effective. Preliminary studies indicate, however, that it has little effect on removing dissolved inorganic micronutrients such as ammonia, nitrite, nitrate or phosphate. Because of the various materials used to produce activated charcoal, further research is needed to make a comparison of their adsorptive characteristics.

Working in conjunction with the Microbiology/Pathology Program area, ammonia production rates of *Artemia salina* and *Homarus americanus* have been determined under various environmental conditions. Ammonia is a primary waste product of both these animals, in addition to being toxic at low concentrations and, therefore, of concern to crustacean aquaculturists.

Larval biology

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

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

Microbiology/pathology

The task of the Microbiology/Pathology Group at BML is to identify potential and existing disease conditions and to recommend prophylactic or therapeutic measures. Description of work done during the past year is best treated in three segments: *(A)* general, *(B)* lobster (*Homarus americanus* and *H. gammarus*), and *(C)* Dungeness crab *(Cancer magister).*

A. The microbiological quality (numbers and types of organisms) of water used for cultivation is a good index of the efficacy of control and maintenance procedures. Further, a shift in the proportion of microbial types (for instance, chitinolytic organisms) would increase the disease potential. To ascertain the biological water quality, all cultivation systems are monitored by determining the total viable bacterial count. In addition, during the past year procedures have been developed to differentiate isolated bacteria and to determine the ratios of major morphological and physiological groups. A collection of potentially pathogenic chitinolytic bacteria has been started and a tentative classification of these organisms has been initiated. Pathogenic fungi are continually maintained for comparison with new isolates.

B. Gross morphological and histopathological changes have been examined from dead and sacrificed lobster from experimental and holding systems. Scanning electron microscope procedures have been established for examination of the exoskeleton of juvenile lobster afflicted with a possibly new form of "shell erosion." Experiments have been conducted to determine morphological changes (macro- and microscopic) of the hepatopancreas in response to altered diets. The rate of ammonia production of juvenile lobster has been established over the entire molt cycle.

C. The decline of the Dungeness crab fishery in central California has led us to study the relationship of epibiotic fouling to egg mortalities observed in nature. We have been able to determine that epibionts, especially non-filamentous bacteria, can cause major egg mortalities on captured females. We believe this condition also occurs extensively in nature, on the basis of comparative studies that have shown a strong correlation between the type of distribution of egg mortalities found in nature and those in the laboratory caused by microbial epibionts.

Crab larvae cultivated in the central California area have a similar disease condition that greatly reduces their chances of survival. We have found that the use of antibiotics increases the survival rate of larvae more than five times. This is also highly indicative of bacterial epibionts which may affect crab larvae in nature as well. Further study has determined the therapeutic levels of several different antibiotics, and we have been able to greatly increase the survival of static culture of the larval stages.

Nutrition

The BML's Nutrition Program's overall goal is the definition of enough nutritional parameters of the lobster, *Homarus americanus*, so that least-cost formulated diets can be readily produced to meet the needs of a commercial culture situation. The development, this year, of a feeding regime, that for the first time matches the growth and survival obtained with a diet of live adult brine shrimp, represents a significant step in the achievement of our goal.

This new feeding regime will also allow for the more rapid definition of specific nutrient requirements. An example of this is our present work on "shell disease." Under selected experimental conditions, juvenile lobsters fed one of our standard pelletized diets suffer a mortality rate of over 70 per cent within a 20-day period. These mortalities are due to a breakdown in normal epicuticle formation allowing bacteria to attack the underlying cuticle or "shell." Supplementation of the standard diet with small amounts of beef liver completely eliminates the "shell disease syndrome." The testing of specific purified compounds in future experiments may lead to the identification of the nutrient(s) required for elimination of shell disease.

Another advantageous feature of this supplemented feeding regime is the very low total pigment level. Lobster grown on this new regime lack pigmentation, although their growth and health are comparable to those of the pigmented lobsters grown on brine shrimp. These nonpigmented animals provide an excellent test situation for the termination of pigment requirements.

On a broader scale, a cooperative experiment that is being carried out by both San Diego State University and Bodega Marine Lab has pinpointed a number of unsuspected problems. These problems relate to different systems designs and prevent the immediate inter-laboratory calibration of dietary studies. After suitable modifications, these cooperative experiments will be continued and expanded to cover the entire growth period to market size.

Along with the above studies of nutrient requirements, we have continued to examine the lobster's food consumption in relation to the various environmental factors of culture. Experiments carried out with shrimp tail muscle and pelletized rations agree well with our earlier studies using live brine shrimp.

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Cooperating Organizations

Brigham Young University, Department of Biology, Provo, Utah

California Fish and Game Department, Granite Canyon Lab., and Menlo Park Office, California

California North Coast Regional Water Quality Control Board, Santa Rosa, California

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

Foremost Foods Company, 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, Alaska

San Diego State University, Department of Biology, San Diego, California

San Francisco Bay Brand, San Francisco, California

University of the Pacific Marine Laboratory, Dillons Beach, California

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

Optimization of an Artificial Diet for Lobster Culture

Dublin
R/A-20

R. Barry Holtz

The objectives of this project were to formulate artificial dietary rations for lobster feeding, using an experimental plan based on Response Surface Methodology (RSM). Diets were chemically analyzed to confirm their nutritive content.

A five-level, five variable RSM experiment (5 x 5) was formulated with the assistance of Dr. Douglas Conklin, Bodega Marine Laboratory. A total of 32 dietary plans were developed. Approximately 18 kg of each formulation was prepared in the Foremost Foods Research Center's pilot plant, and approximately 2 kg of each dietary formula was extruded at the Bodega Marine Laboratory.

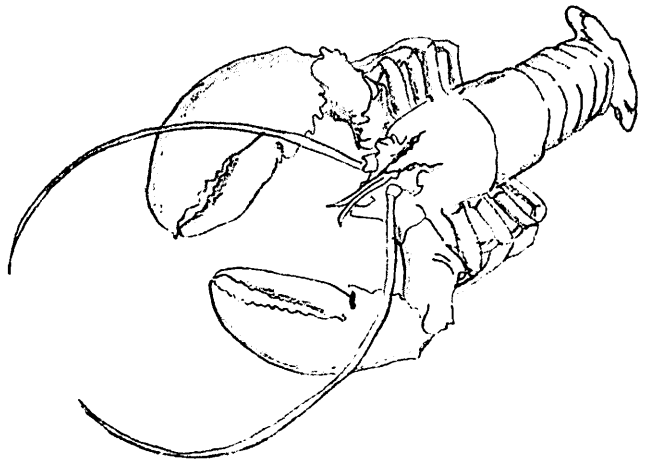
A 120-day feeding experiment was completed at Bodega Marine Laboratory using these diets, and a second feeding trial was initiated at San Diego State University to establish the effect of lobster rearing conditions in order to allow interlaboratory calibration of the planned dietary studies.

The San Diego feeding study was terminated at the end of four months when a preliminary analysis of the data indicated that differences in the rearing systems design between Bodega and the San Diego facilities were causing a significant difference in response to the dietary studies. A computer analysis by RSM of the San Diego study will be performed on receipt of the trial data from San Diego State.

The RSM analysis of the Bodega trials did identify an optimum diet which indicated a moderate increase in growth performance over brine shrimp. Attempts to manufacture this formulation by current processing procedures did not produce a physically stable product. Further work is planned to define a manufacturing process which will ensure pellet integrity of this optimized formulation. Manufacturing processes will also be explored to prevent leaching of vital nutrients from the pelletized feed when introduced into the rearing system. Recent experiments by Bodega personnel have found this to be an essential requirement of an artificially prepared diet formulation.

Cooperating Organizations

Bodega Marine Laboratory
Foremost Foods Company, Research and Development Center, Dublin, California
San Diego State University, San Diego, California



Use of Thermal Effluent in the Culture of Crustacea and Fishes

Jon C. Van Olst and Richard F. Ford

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

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

The major objectives of this continuing program have been to develop a commercially feasible production system for the American lobster and to assess the benefits and problems involved in using thermal effluent as an economical source of heated water.

The research is being conducted in laboratories at two generating stations – the Encina Power Plant of the San Diego Gas & Electric Company, and the Redondo Beach Generating Station of the Southern California Edison Company. Other related experiments are conducted in the San Diego State University aquaculture laboratory at the Scripps Institution of Oceanography. Considerable matching support for the research program has been provided by both the Research and Development Program of the Southern California Edison Company and the San Diego Gas & Electric Company.

This work is part of an integrated and carefully planned Sea Grant program to develop commercially viable lobster culture throughout the United States. Major areas of investigation include: 1) the use of thermal effluent to accelerate growth rates; 2) the effects of various temperature and photoperiod regimes on growth; 3) the physiological effects of potentially toxic substances from industrial pollution or culture system materials on lobsters cultured in thermal effluent; 4) the development of suitable artificial foods in cooperation with scientists at the Bodega Marine Laboratory and the Foremost Research Center; 5) energetics and food conversion studies; 6) development of more efficient techniques for communal rearing of lobsters; 7) evaluation of an *H. americanus* × *H. gammarus* hybrid for use in commercial culture; 8) development of methods and systems for the individual rearing of lobsters to market size; and 9) economic studies of the commercial feasibility of lobster culture.

Temperature effects

We have been successful in culturing the American lobster to a market size of one pound (454 g) on a diet of natural foods (Fig. 1). This was accomplished in as few as 42 months in seawater of ambient temperature. More rapid growth has been observed in experiments in which thermal effluent from coastal power plants was used to provide sea-

Fig. 1. American lobster, *Homarus americanus*, cultured from the egg to a marketable size of 1 lb in approximately 42 months

water of elevated temperature. In a 360-day experiment, comparing growth of sibling lobsters under otherwise identical conditions, lobsters held in ambient-temperature seawater (19.5°C) reached a mean weight of 16.3 g and those held in thermal effluent (22.0°C) reached a mean weight of 21.5 g. Similar research by colleagues at the Massachusetts State Lobster Hatchery indicated that American lobsters achieved a mean weight of only 2.6 g after one year of culture at ambient Atlantic temperatures (approx. 9-10°C).

Growth rates have been increased considerably through the use of thermal effluent. We have demonstrated that growth and survival of lobsters held in thermal effluent are the same as for lobsters held in seawater warmed to effluent temperatures with electric heaters. This indicates that no toxic chemical effects are present in the effluent, a conclusion that has been verified by careful chemical analyses of the trace levels of heavy metals and chlorinated hydrocarbon compounds present in the seawater and in the tissues of cultured lobsters. Thermal effluent appears to be a useful, inexpensive source of warmed seawater which can be safely employed in lobster culture.

Further studies of the usefulness of thermal effluent have been conducted this past year. Effluent temperatures fluctuate with daily electrical demand placed on the generating units, with seasonal variations of intake water temperatures, and as generating units are shut down for maintenance. In addition, it is seldom possible to hold temperatures constant in large aquaculture production systems. For these reasons, studies have been done concerning the effects of abrupt temperature changes on growth, molting and survival of juvenile lobsters. Sudden decreases to temperatures of 8°, 5° and 2°C were not detrimental to the lobsters. Further, the shock of temperature decreases to 5° and 2°C acted as a stimulus to promote molting in these groups, so that the intermolt periods were reduced by approximately 50 per cent over those of control groups. Increase in carapace length at molt were not affected. It is possible that the temperature decrease simulates an abbreviated winter period or some other natural condition that may regulate the development of new cuticle and other events leading to molting. Thus, temperature fluctuations might be used purposefully to promote more rapid growth. Such temperature manipulations on a large scale could be done easily in a commercial production facility at a generating station, because large quantities of both cool and warm water are available.

Reproduction and hybridization

Several controlled matings between lobsters were performed in our laboratories this past year. A few produced viable, free-swimming larvae. Shortly after the female sheds her old exoskeleton, she is docile and can be impregnated by the male. In approximately three months at temperatures of 22°C, the female will extrude eggs and cement them to the pleopods on her ventral abdominal segments where they continue to develop prior to hatching about four months later. Many females have been brought to this condition; however, for unknown reasons, most have lost their eggs during the period of development between extrusion and hatching. We are now starting experiments that should help evaluate the cause of this incomplete development.

The American lobster, *Homarus americanus*, and the European lobster, *Homarus gammarus*, are both known to reproduce successfully in captivity. Previous results have shown that *H. gammarus* are generally larger than *H. americanus* at each stage of development. This difference begins with a larger egg, and the greater size is maintained throughout the juvenile stages.

Recently these two closely related species have been hybridized (Fig. 2). A comparison of the growth rates of the progeny from these crosses with the parental type was conducted. Studies concerning growth and survival of the larval and juvenile stages reared individually at constant elevated temperature showed that both the hybrid and the *H. gammarus* juveniles were larger and grew at a slightly more rapid rate than did the *H. americanus*. Some evidence of hybrid vigor was apparent in the growth rates of the cross. The growth of *H. gammarus* was nearly equal to that of the hybrids, but its survival was much lower.

Communal rearing

Due to the solitary and aggressive nature of the American lobster, cannibalism is a major factor contributing to low survival and more variable growth in communal rearing systems. We recently completed a series of experiments to assess the possibility of using communal

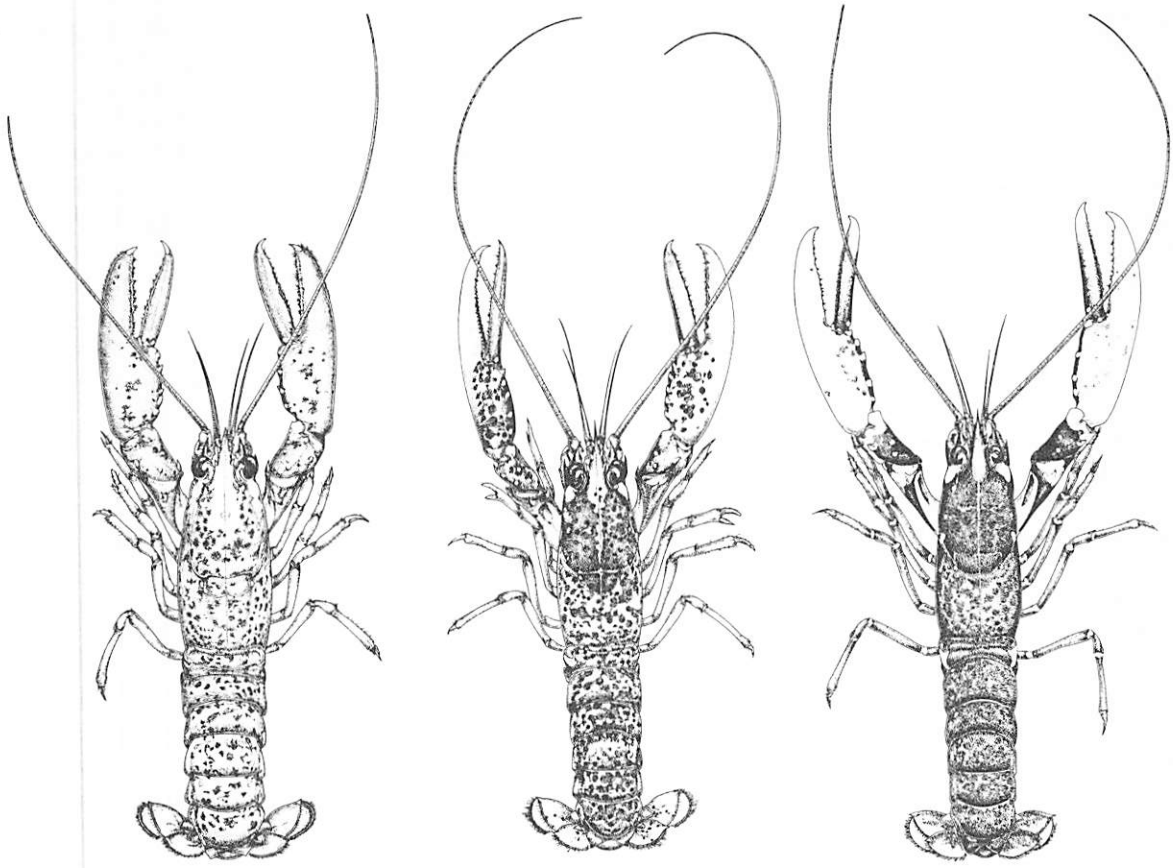


Fig. 2. Cultured six-month old juveniles of *Homarus americanus* (left), *Homarus gammarus* (right) and a hybrid of these two species (center)

rearing for the commercial culture of post-larval and small juvenile lobsters. Culturing lobsters of these sizes in individual compartments has thus far produced greater survival than in communal rearing systems. However, from an economic standpoint, the labor and equipment to maintain individual rearing containers for these early stages may be prohibitively expensive in commercial production. Considerable savings could be realized by using communal rearing for this phase of the culture process if survival in such systems can be improved.

We have investigated many of the components of the communal rearing environment in an attempt to identify and eliminate characteristics of the system that contribute to poor survival and variable growth. This year we conducted experiments to determine the best stocking density, substrate type, water temperature, food type, and photoperiod regime to produce optimum growth and survival of lobsters reared communally. We have tested new substrates with suitable refuges to reduce the number of social encounters that lead to fighting and cannibalism. One important result showed that refuges with a rear entrance provided an escape route for smaller individuals threatened by dominant lobsters, and also contributed to more efficient water flow and waste removal. Significantly higher survival and less variable growth resulted from the use of three-dimensional substrates that allowed the lobsters to utilize the entire water column for refuge. Survival also was improved by using an initial stocking density of approximately 100 juveniles per square meter and by modifying the photoperiod. From previous experiments we know that *H. americanus* is nocturnal and spends most of the daylight hours in its shelter or burrow. During the nighttime foraging period social interractions, including fighting and cannibalism, increase. Increasing the "daylight" period to 18 hours or more caused the lobsters to remain in their shelters longer, and as a result reduced the rate of cannibalism during the abbreviated "nighttime" foraging period.

Nutrition

Due to the high cost of live brine shrimp used as food for lobsters, suitable and less costly artificial diets are being developed and evaluated. Previous experiments have shown that pelagic red crab meal is useful as a supplement in commercial marine shrimp diets. This year we expanded the study to investigate the use of euphausiid shrimp as a dietary supplement. Euphausiids have a broader worldwide distribution and are being fished commercially along the west coast of Canada. Experimental fishing also is under way in Monterey Bay, aimed at developing a commercial fishery for euphausiids. Preliminary results suggest that freeze-dried euphausiids offer a suitable substitute for the crab meal and may provide even higher content of carotenoid pigments.

We have continued to work in cooperation with other California research groups to develop an artificial pelletized diet that meets the nutritional requirements of the lobster, can be produced at low cost, and that has the appropriate physical characteristics for distribution and stability when used in production systems similar to those that would be used commercially. The project involves diet formulation at the Bodega Marine Laboratory, analysis of ingredients at the Foremost Research Center, and evaluation in long-term feeding trials in our laboratory at the Scripps Institution of Oceanography. Preliminary results from the first of these evaluations suggest that growth rates equal to 80 per cent of those achieved by feeding live adult brine shrimp can be attained with the best dry pelletized diets developed in this research program. These results are encouraging and suggest that artificial diets superior to brine shrimp can be developed in the near future.

Culture systems

The high levels of fighting and cannibalism observed in American lobsters dictate that for the larger part of the culture period the animals must be held separate in order to avoid losses. Experiments were conducted to assess the dependence of growth, molting frequency, and survival on the amount or horizontal surface area provided for each lobster. Eight sizes of individual containers ranging from 6-750 cm^2 were provided. Parallel experiments were conducted in containers made of both transparent and translucent materials to evaluate the effects of visual communication. The experiments have been in progress for 24 months. Growth and survival were severely reduced in the smaller rearing containers, while molting frequency was less affected (Fig. 3). Visual communication with other lobsters had no apparent effects on growth or survival. Equations describing the relationship between space and growth are being developed. Estimates are being made concerning space requirements as they would affect production costs in commercial lobster culture.

Individual rearing systems for lobsters and similar crustaceans are of three types. Two-layered systems provide an array of rearing compartments one layer deep. Layered, two-dimensional systems employ several arrays of compartments oriented vertically, but each layer is located in its own separate tray or tank of water, so that each animal has an air-water interface above it. Three-dimensional systems consist of stacks of layers of individual rearing units immersed in one or more deep tanks or raceways.

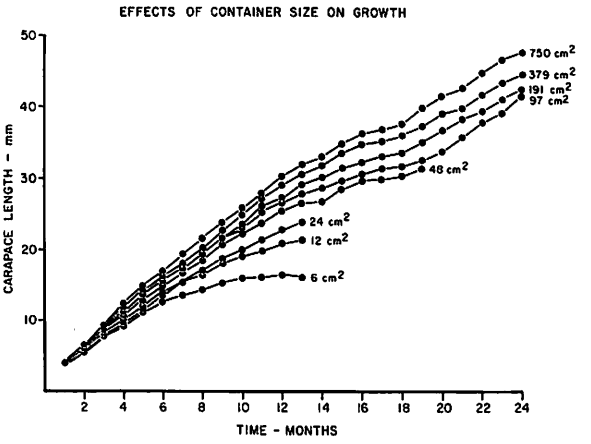


Fig. 3. Growth of eight groups of 50 lobsters, each held in individual culture containers with horizontal surface areas ranging from 6-750 cm^2

In areas where land costs are relatively low, the production facility could be spread out to accommodate a single layer of rearing units. Such two-dimensional systems offer the advantages of a high surface to water volume ratio for oxygen transfer and convenient, unrestricted access for monitoring, stocking, feeding, and harvesting. However, most coastal property in North America is extremely expensive, and it probably will be necessary to make more efficient use of limited space.

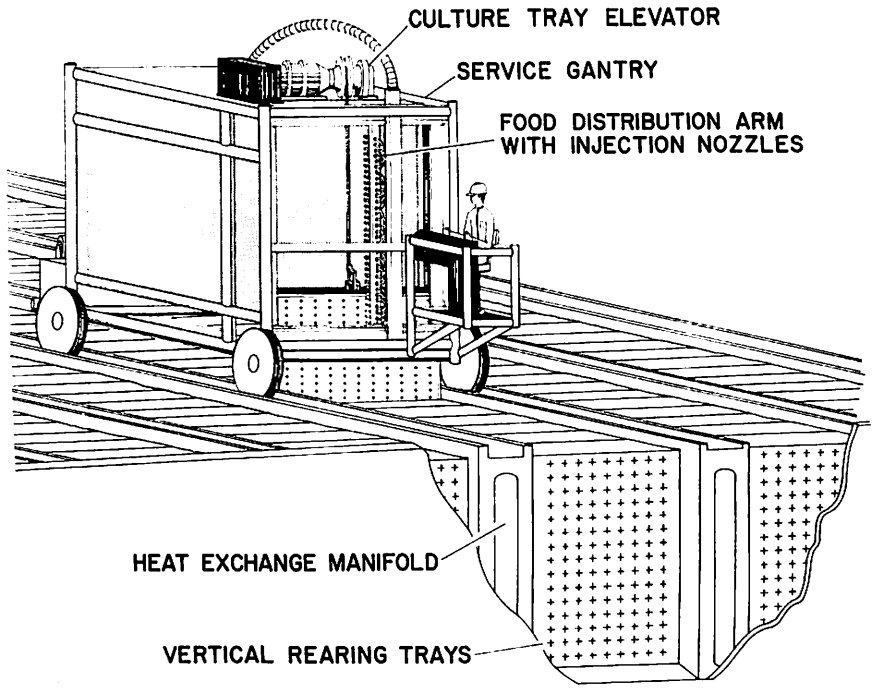


Fig. 4. Deep tank lobster culture system. Artist's conception indicates traveling gantry used for lifting, feeding, and harvesting vertically oriented culture trays which would be suspended in long concrete raceways. A prototype of this system is currently being evaluated

One method of utilizing vertical space is simply to arrange shallow culture trays in multiple level racks. One system adaptable for this approach is our flushing tray, which can be stacked using commercially produced, cantilevered warehouse racking material. The system also provides for relatively convenient access and high surface/volume ratios, but appears to be wasteful and expensive, because a separate tank is necessary for each level. This layered, two-dimensional system may be most useful in holding especially valuable animals such as brood stock, which would need to be examined and moved frequently during the culture operations.

Three-dimensional, single-tank systems appear to offer a more economical alternative, because they require little land area and the holding tanks used are inexpensive. A promising three-dimensional system developed at San Diego State University consists of a large, deep holding tank in which perforated rearing container units are hung vertically, as shown by an artist's conception in Fig. 4. The containers are lifted vertically out of the holding tank by an overhead winch or gantry so that feeding, stocking, and harvesting can be accomplished efficiently. Food is introduced through food injection nozzles which slip through flexible openings in the vertical face of each container. Growth and suvivorship studies of lobsters held in a prototype of this system are currently in progress. If they prove successful, the deep tank system for individual culture of lobsters will be evaluated on a more detailed basis for its applicability to commercial-scale lobster farming. If preliminary estimates are accurate, extremely high holding densities appear feasible, perhaps as high as 73 kg/m^2 of bottom area, in concrete raceways 3 m wide and 3 m deep. The major disadvantages of relatively low surface area/volume ratios and inconvenient feeding and harvesting can be compensated for, we believe, by incorporating several recent technological innovations.

The deep tank design appears to be a promising three-dimensional, individual culture system. It offers the relatively low initial costs of other three-dimensional systems. Because the trays are lifted out daily for feeding maintenance, a close watch can be maintained for disease, overfeeding, and mortalities. In addition, the concrete raceways in which the

vertically oriented trays are suspended can be constructed partially or entirely underground, to reduce both construction costs and problems with building height regulations and to improve insulation of the system against heat loss. Further evaluations of our flush tray and deep tank systems should provide the information necessary to assess the commercial feasibility of lobster culture.

Production cost projections

In cooperation with the aquaculture modeling group at the Bodega Marine Laboratory, we have developed further information to indicate the usefulness of thermal effluent in lobster culture. Production costs were estimated for commercial facilities which might be located in northern or southern California, and New England. In all cases, the direct use of thermal effluent in the culture system yielded the lowest total production costs and the shortest production times. In addition, test cases were developed based on indirect use of the waste heat through heat exchanger systems, which our previous results indicate would not be required. However, even with this limitation, the indirect use of thermal effluent resulted in the lowest production costs.

The lowest production cost was $2.56 per pound, for lobsters cultured in thermal effluent at a site in southern California. The current wholesale price on the West Coast frequently exceeds $3.00 per pound. Thus, it appears that the systems and methods we have developed for lobster culture may now be economically feasible. Further evaluations on a pilot scale will be necessary to test the commercial feasibility of lobster culture accurately.

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Cooperating Organizations

Massachussetts State Lobster Hatchery, Martha's Vineyard, Massachussetts

National Marine Fisheries Service, La Jolla, California

San Diego Gas & Electric Company, San Diego, California

San Diego State University Foundation, San Diego, California

Southern California Edison Company, Los Angeles, California

St. Andrews Biological Station, Canadian Fisheries and Marine Service, St. Andrews, New Brunswick, Canada

Protective Measures for Shellfish Aquaculture

Harriette C. Schapiro and James F. Steenbergen

The cellular response was established as the primary defense in lobsters. Phagocytosis was markedly decreased at elevated temperatures. Characterization of *Leucothrix* by serology, DNA melting profiles and electrophoresis was continued. Gram-negative bacterial infections and exoskeleton lesions continue to be the major problems found in autopsy specimens.

A number of disease problems are now recognized in crustacean aquaculture systems. Gaffkemia, a fatal bacteremia in lobsters, causes epizootics in the wild, in impoundments, and in aquaculture systems. *Leucothrix*, a filamentous bacterium, is associated with significant losses in larval and juvenile stages of lobsters and shrimp. A number of strains of gram-negative bacteria have been isolated from the hemolymph of moribund lobsters sent to us for autopsy. External lesions ("shell disease") occur in lobsters, crabs and shrimp held in aquaculture facilities.

In our earlier investigations of gaffkemia, we demonstrated that adult American lobsters *(Homarus americanus)* can be protected against gaffkemia by immunization with live avirulent strains of the pathogen (*Aerococcus viridans*). We have developed an *in vitro* system for the assessment of phagocytosis by lobster hemocytes. This technique enabled us to determine that protection of the lobster is accompanied by an increase in numbers of phagocytes, indicating that phagocytosis is the major defense mechanism in lobsters.

One of the goals of aquaculture is to enhance the growth rate of the American lobster by use of elevated temperatures. Unfortunately, disease problems are more prevalent at higher temperatures. Since the primary defense against infection is phagocytosis, we tested the effects of temperature on our *in vitro* lobster hemocyte system. Preliminary results, reported last year, indicated that little or no phagocytosis occurred at 24°C. Further studies have shown that phagocytic activity is unimpaired up through 20°C. At 22°C and above, phagocytosis is severely depressed. This means that although higher growth rates may be achieved above 20°C, disease resistance of the animals at 22°C and above may not be adequate to prevent infection. Other physiological parameters may also be affected adversely by elevated temperatures. Thus, aquaculture efforts at temperatures above 22°C may not be economically feasible.

Our studies on the mechanism of pathogenicity of gaffkemia were concluded with a chemical comparison of the cell walls of virulent and avirulent forms of the pathogen. These bacteria are qualitatively very similar, but differ significantly in their effect on the lobster. Virulence is apparently determined by the chemical similarity between the outer layers of the bacteria and the lobster hemocytes. Hence, disease results when the phagocytes are unable to distinguish the virulent bacteria as foreign material.

Isolation of *Leucothrix*

We previously reported the development of a selective medium for the isolation of *Leucothrix* from crustaceans. Strains of this bacterium isolated from lobsters and shrimp were compared to known cultures from the American Type Culture Collection by serological analysis and by DNA melting profiles. Our results confirm that the lobster epibiont is *Leucothrix mucor*, while the shrimp isolate may be a previously undescribed *Leucothrix* sp. In response to disease problems in juvenile lobsters, we developed antibiotic treatment with neomycin which has proved efficacious in treating the infestations. The poor antigenicity of these bacteria precluded the development of highly specific fluorescent antisera for ecological studies. We are currently using electrophoresis techniques to study surface proteins for ecological work.

We have continued to isolate gram-negative bacteria from the hemolymph of stressed lobsters. Pure cultures of these isolates have been maintained in lyophil, and are available for more extensive studies in the eventuality that such diseases become a more serious problem.

Exoskeleton lesions are often observed in autopsy specimens. These infections may be primary or secondary, and either kill the

animal or produce unsightly lesions, which lower the market value. The lesions are caused by a complex succession of microorganisms, which hydrolyze the lipids in the epicuticle, then the chitin of the exoskeleton, and finally penetrate the hemocoel. Work in this area is continuing.

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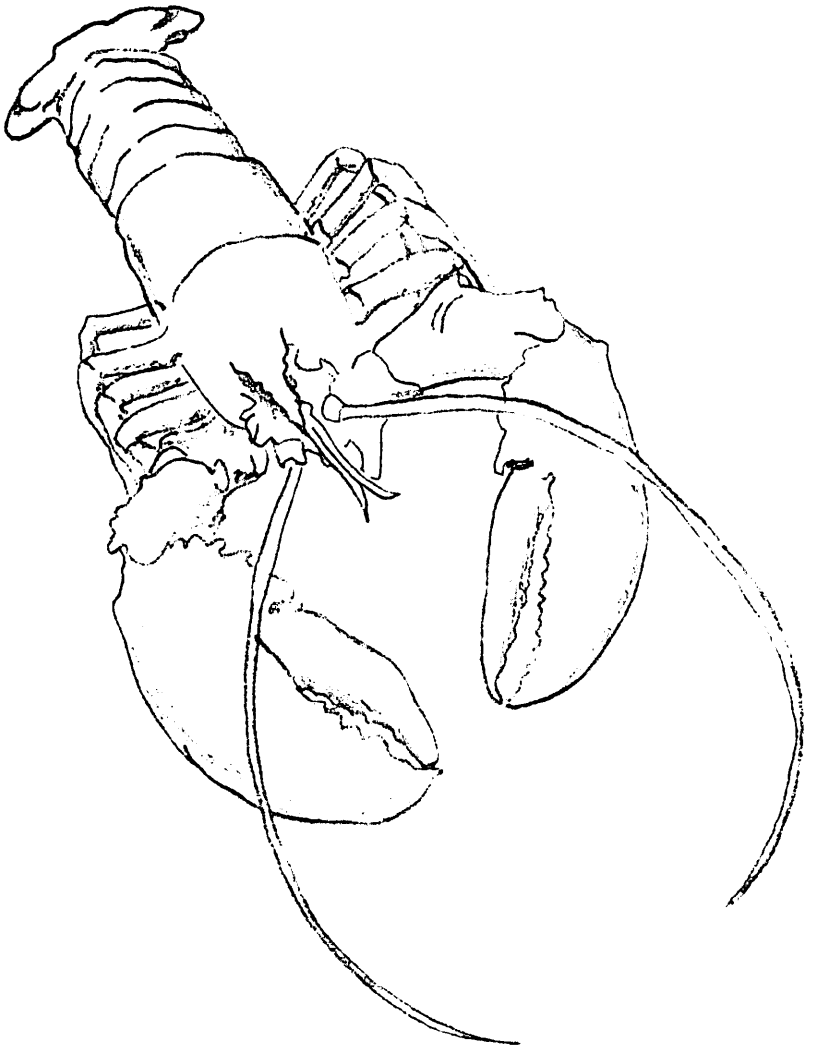

Biochemical and Genetic Control Applied to the Critical Stages in Culturing Abalone

Daniel E. Morse

With techniques for the efficient control of abalone reproduction now available, e.g., hydrogen peroxide induced spawning, the principal remaining recognized barrier to the economic development of the abalone mariculture industry is the high post-larval mortality of abalones under hatchery conditions. Our objective has been to identify the principal causes of this mortality, and to develop solutions to this costly problem.

In experiments performed with uniformly healthy batches of abalone larvae (obtained with our previously developed peroxide-induction technique; see last year's Report), we have during this past year obtained strong quantitative evidence that:

1. A major cause of post-larval abalone mortality is an arrest (or delay) of rapid and complete morphogenetic development, followed by eventual bacterial overgrowth.

2. Settling behavior ("substrate selection"), metamorphosis, development, and subsequent growth can be induced to proceed rapidly and with exceptionally high success, in populations of very young (three-day old) abalone larvae, upon exposure to "nursery rocks" covered with crustose coralline red algae. (These rocks and their associated algae have been identified recently, by Dr. Mia Tegner at SIO, and ourselves, as characteristic of the natural "nursery grounds" of juvenile red, pink, and black abalone off the southern California coast.) We have found that these rocks and their associated algae provide: (a) the inducer for rapid and successful substrate selection and metamorphosis; (b) a preferred and secure substrate (which, with the developing coloration of the growing abalone, becomes camouflaging as well); and (c) a source of preferred food, supporting active grazing and the rapid development and growth of settled and metamorphosed abalones. Animals which have not been exposed to the algal inducer remain as actively swimming (behaviorally and developmentally arrested) larvae; these suffer progressive deterioration and death, with only slow development of relatively few survivors. In contrast, young abalone larvae "triggered" by exposure to the algal inducer quickly cease swimming, settle upon the algae, undergo rapid physical metamorphosis, and begin successful feeding on the algal surface.

3. No other species of microscopic algae, diatoms, or macroalgae we have tested (including several species presently in use in hatchery-practice, and others specifically suggested to us for investigation, including the locally abundant diatom *Cocconeis*) have proved effective in inducing settling, metamorphosis, or survival of abalone larvae.

4. Very early, cost-efficient transplantation of "triggered" and pre-settled abalones now appears feasible. A reduction in hatchery costs for the production of seed abalone should also be possible, based upon these findings.

Other conclusions

Our experiments also prove that the abalone larvae require no food. Their very rich endowment of yolk (from the egg) provides adequate nourishment to maintain the growing larvae in a state of full "competence" for metamorphosis and survival, provided that the algal inducer is presented sufficiently early.

Similarly, our experiments show, previous difficulties in obtaining high rates of settling, metamorphosis, and survival cannot be due to a (sometimes-invoked) "congenital variability" in competence, or a "high frequency of genetic errors," in the gametes. Gametes and larvae of uniformly high competence are obtained with our peroxide-induction technique, and simple cultivation conditions. Growth of bacteria and other microorganisms can be controlled (without chemical antibiotics) with adequate water quality, and rapid induction of metamorphosis and growth by early presentation of the algal inducer and food.

It remains to be determined how applications based upon these findings may best be implemented in the hatchery-cultivation of abalone, and in the early transplantation of pre-settled young seed abalone to oceanic environments.

Acknowledgements

In the course of our experiments, we have collaborated closely with governmental, commercial, and community agencies and groups in both the United States and abroad. In California, we have worked especially closely with the Ab Lab (Port Hueneme), the Operations Research Laboratory of the California Department of Fish and Game, the Department of Fish and Game-Sea Grant Cooperative Program in Experimental Abalone Reseeding, University of California Extension-Sea Grant Advisory Services, the Santa Barbara County Department of Parks, and the Santa Barbara Mariculture Foundation. Staff members of the National Museum of Natural History at the Smithsonian Institution (Washington) are assisting us in our studies of the coralline red algae which induce "substrate selection" and metamorphosis of abalones.

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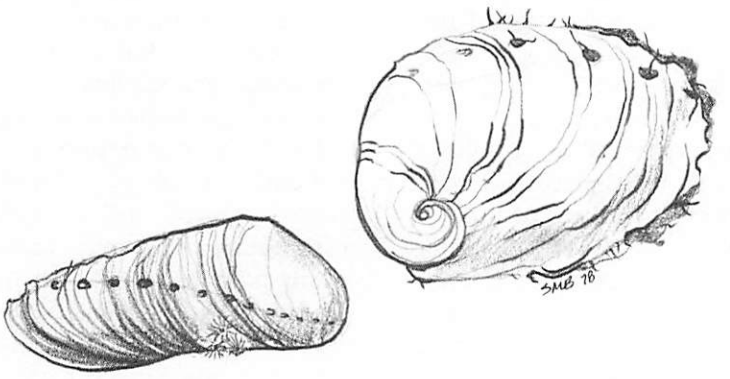


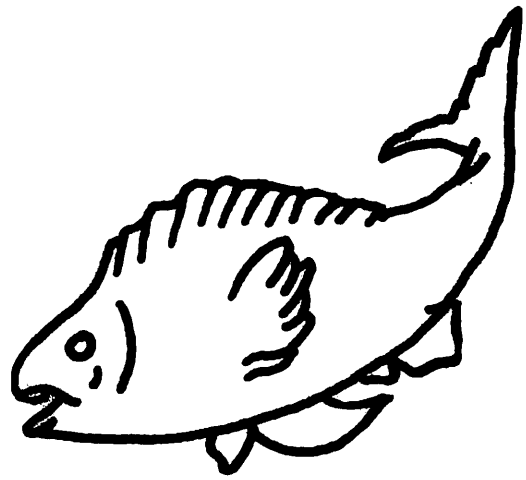
Surfperch Mariculture

Kenneth S. Norris

A small-scale mariculture system for the live-bearing striped surfperch, *Embiotoca lateralis*, is being maintained on the campus at UC-Santa Cruz. During the year, we have gathered data concerning the precise timing of the reproductive cycle and developmental period in *E. lateralis*, in hopes of adapting the animal to controlled laboratory conditions. We have also progressed toward the quantitative description of an energy budget for this species. Information on caloric values of prey items and growth rates of fish has allowed us to optimize feeding regimes in captive animals.

Domestication of the striped surfperch proceeds along a somewhat difficult path. The identified obstacles are associated mostly with the maintenance of a dependable, trouble-free laboratory environment for the animals, while sufficiently minimizing costs to make the system profitable. Mechanical difficulties and problems associated with relocation of the laboratory during this year detracted from the time available for working with the animals themselves to speed the domestication process.

Oxygen bomb calorimetry has proven to be an accurate, reliable, and revealing tool in the study of energetics and nutrition. It was used in this project to determine caloric values of food items and energy requirements of captive fish. This work will be continued until the end of 1977, along with further attempts to maintain individual animals for long periods of time.



Aquaculture of the Purple-Hinge Rock Scallop

Charles F. Phleger and David L. Leighton

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

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.

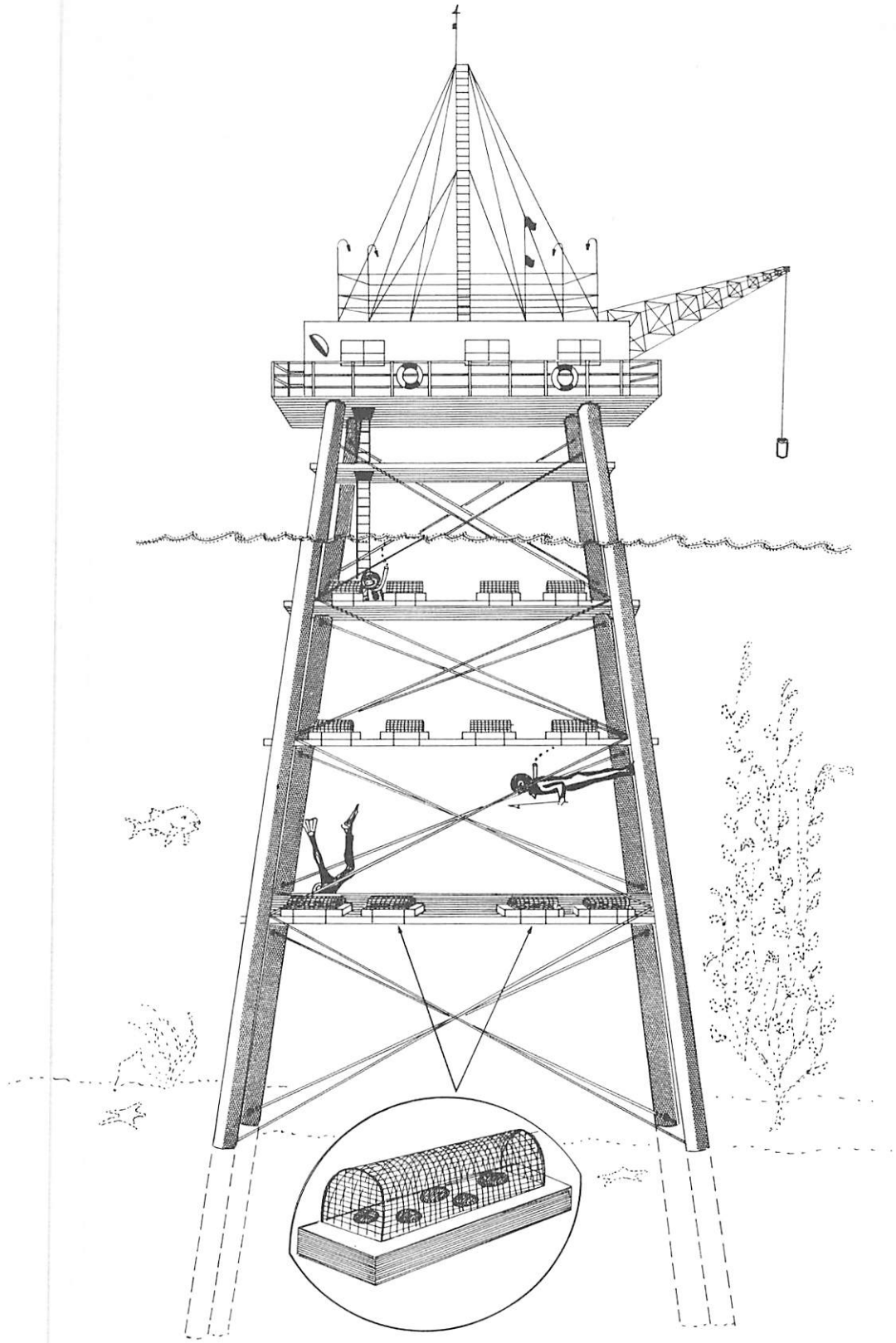
This study, encouraged by results of a preliminary investigation in 1972-74 (Leighton and Chess, unpublished), is exploring pertinent aspects of *Hinnites* biology including reproduction, requirements for larval culture, substrate preference, natural foods, tissue chemistry, and growth rates in a wide variety of natural environments ranging from bays to the open sea at depths from five to 130 meters. Five students, conducting work toward graduate degrees, are now engaged in studies related to *Hinnites* aquaculture. Our Sea Grant trainee for the year has completed his Master's degree program at SDSU on the reproductive biology of this shellfish.

Progress to date

Aspects of the culture and biology of *Hinnites* receiving most attention this year include: 1) further resolution of reproductive cycles in local populations; 2) development of a reliable technique to induce spawning; 3) testing additional food organisms for larvae, and refining methods for larval culture; 4) completion of a year's observations on growth of juvenile and young adult scallops at several depths and concentrations on pilings of the Naval Ocean System Center Tower, of the U.S. Navy, off Mission Beach (see Figure) and under semi-protected conditions in Quivira Basin, Mission Bay; and 5) improvement in design of growing supports (rearing structures) for extensive culture. New field installations were placed at six stations within Mission Bay, and a series of cages holding scallops were suspended in vertical transect to observe growth rates at depths of eight to 130 meters in deep water offshore. Natural recruitment of juvenile scallops was followed throughout an entire year near the entrance to Mission Bay.

Adults of this dieocious bivalve collected from bay and ocean environments near San Diego throughout 1975-76 were found gravid during both spring and fall in Mission Bay, and in summer and winter offshore (Jacobsen, 1977). A reliable technique was adopted for induction of spawning (that of Uki and Kikuchi, 1974, using UV irradiated seawater) and will be described elsewhere. Mature scallops have been found in prime condition and responsive to stimulation only during relatively short periods, however, and conditioning to gravidity will now be attempted to assure availability of a reliable brood stock regardless of season.

Our improved culture apparatus should allow higher yields of larvae through metamorphosis. Progeny from an April 1976 spawning reached an average diameter of 14.5 mm at seven months, 26.3 mm at one year, and 53.7 mm at 1.5 years. These averages likely reflect conservative growth rates, since early feeding history was varied and not well controlled. Loss of our floating laboratory has hampered progress in juvenile culture, but emphasis will be placed on prob-



Naval Ocean System Center Tower, located off Mission Beach, San Diego, California, which is being used for open ocean growth studies of the purple-hinge rock scallop

lems associated with early rearing during the current grant year. Most juvenile stock employed in growth studies was collected from natural set found beneath jetty rocks near the entrance to Mission Bay. This population of juveniles has been studied closely to establish seasonal variation in recruitment force and to test the efficacy of our juvenile (or "spat") collectors. Samples taken bimonthly reveal that maximum influx occurs during late spring and summer months. Our efforts in this part of the research were hindered by destruction of the study area this year by jetty reclamation operations. Effective spat collectors have yet to be developed. The labor-intensive practice of gathering juvenile stock by hand would not be feasible in a commercial operation.

Comparative growth observations in bay and ocean environments utilize suspended racks and bottom-secured posts in protected waters, and buoyed lines or pilings of the oceanographic platform offshore (see Figure). Over 1000 juveniles have been introduced to experimental cages at our various stations. Growth rates of juveniles and young adults at depths of 3-10 m at both the platform and Quivira Basin locations have ranged from 4-5 cm/yr. This finding compares favorably with that of Castagna and Duggan (1971) working with *Argopecten irradians*. We project that continued growth of *Hinnites* at this rate would yield a scallop of 10-13 cm after two years in extensive culture. Scallops in that size range have muscle weights of 20-60 g, valued by present wholesale seafood prices at about $0.25/scallop.

Flavor and biochemical studies of adductor muscle suggest *Hinnites* will command market prices competitive with existing scallop products. It was shown, however, that loss of flavor occurred when the animals were starved; therefore, scallops should be processed soon after harvesting from food-rich growing waters.

Scallops experimentally starved had a bland flavor and had lower monosaccharides (0.292-0.511 μ moles monosaccharide per mg protein) compared to that of normal flavor scallops (1.047-1.739 μ moles monosaccharide per mg protein). *Hinnites* differs from the sea scallop, *Placopecten magellanicus*, the Pacific oyster, *Crassostrea gigeus*, and the littleneck clam, *Protothaca staminea*, in that it has more unsaturated fatty acids (93-96 per cent compared to 66-70 per cent for these three species). One of the principal reasons for this is the presence of more 18:2 acids (23-32 per cent). Lipid content of the adductor muscle averages about 2 per cent (as per cent dry weight), of which only about 2 per cent is cholesterol.

Tests for chronic accumulation of heavy metals were begun this summer by Richard A. McClintock, a graduate student in chemistry at SDSU. The preliminary results indicate about a tenfold cadmium enrichment in the gonads-digestive gland (20.4-38.7 ppm) over the whole body (3.9-9.0 ppm) of *Hinnites* collected from San Diego Bay. The concentration of cadmium in the adductor muscle is lower (0.9-1.4 ppm) and fairly constant from one individual to another. Other heavy metals are being "spot checked" to determine any unusual body burdens; these include mercury, copper, zinc, and tin.

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Cooperating Organizations

U.S. Navy

Kelp Bed Mariculture and Resource Management

M. Neushul and David Coon

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

The giant kelp, *Macrocystis*, occurs in the northern hemisphere only along the west coast of North America, where it forms spectacular undersea forests, the plants growing up from depths as great as 80 to 100 feet, to form spreading canopies of surface vegetation. These undersea forests have been harvested for over 50 years, in ever-increasing amounts. With this increase, it has become obvious that a rational management policy is needed in order to optimize the production from the kelp forests, and to provide a steady survey for the two processing plants in southern California. Shortages of kelp during the past year forced kelp harvesters to shut down their processing plants for several weeks. A management plan is also essential to ensure that the overall kelp bed ecosystem, which is the basis for both commercial and sports fisheries, is maintained in a healthy condition. It has been the purpose of this study to outline long- and short-term components for a resource management plan for Californian kelp forests.

During the past two years we have been assembling the basic components of a kelp bed management plan. First of all, it is essential that the major physical factors influencing the plants be measured and monitored over several years, so that typical and atypical seasonal patterns in the coastal oceanographic conditions can be determined. These nearshore oceanographic data have been obtained along with data on plant responses in the kelp forests with season, by direct measurement, aerial photography, and the use of harvesting data.

Fig. 1. Kelp harvesting off Goleta Beach – Photo by Wilfred Swalling

Through the kind cooperation of Stauffer Chemical Company we have been able to obtain harvest yields for the first time. It has been possible to plot for two kelp forests, a yield-per-unit-effort, on the assumption that the kelp harvester attempts to maximize his yield per unit time in any kelp forest being harvested (Fig. 1). There is a striking seasonal pattern in these data, with clear optimal and sub-optimal seasons, for the kelp forests.

Individual plant growth studies

The seasonality of kelp forest yield is, of course, an expression of the collective responses of many individual plants. We have been studying the growth of individual plants. In nearly all kelp growth studies done previously the kelp frond is measured. In our studies, we have found that the fronds of *Macrocystis* can grow at very different rates, depending on their position on the basal branching system and other factors. Thus a frond-based growth study must be based on a very large sample in order to average out this built-in error. We have elected to measure the growth of all the fronds on single plants. These whole-plant growth figures give us considerable insight into the role of the basal branching system, and have posed a number of questions about the internal allocation of resources in the kelp plant, as it grows. Obviously a clear understanding of the effects of environmental conditions on kelp growth is essential in any attempt to manage the kelp forests.

A management plan must also take into account the natural rates of recruitment, and the effect of environmental factors on this process as well, since the kelp plants themselves have finite life spans. With an improved concept of how the kelp plants are adapted to their habitat, it follows that genetic selection for incrreased yield, or for specific morphological or physiological characteristics, can proceed.

Our success in learning how to store the germ-plasm of the kelps, and to hybridize from these stocks, has shown that it will be possible to breed and raise defined genotypes. We have done this twice to date by breeding specific plants and then rearing them to reproductive maturity, both in laboratory tanks and in the sea. We are continuing this work. Our studies of kelp gametophytes and hybridization are dealt with in two papers, one in press (Sanbonsuga and Neushul) and one recently submitted for publication. The abstract of this second paper is given here:

Light and Temperature Demands for Growth and Reproduction of Laminarian Gametophytes in Southern and Central California

K. Lüning and M. Neushul

The gametophytes of nine Laminarian species (four from southern California, and five from central California) became fertile in the unicellular stage (female gametophytes) or in a few-celled stage (male gametophytes), when appropriate temperatures and a sufficiently high quantum irradiance in the blue part of the spectrum were supplied. Vegetative growth, leading to the formation of filamentous gametophytes was light-saturated at relatively low irradiances (4 W m^{-2}; equivalent to about 2 nE cm^{-2} s^{-1} or an illuminance of 1000 lux), whereas two to three times this irradiance in continuous fluorescent cool white light was needed to induce the majority of the gametophytes to become fertile. An illuminance of 8300 lux did not inhibit the development of the gametophytes from southern Californian species. *Egregia menziesii* exhibited an exceptionally low quantum demand for induction of fertility. Gametophytes of species from central and southern California differed in regard to their temperature optimum for growth (12°C in the former, 17°C in the latter) and their upper temperature limit for reproduction (17°C in the former, 20°C in the latter).

International seaweed symposium

A portion of our efforts over the past year has been devoted to the IXth International Seaweed Symposium, held at UC-Santa Barbara last August. Over 800 persons attended and over 500 papers were formally presented at these meetings. We presented papers at these meetings on the growth and reproduction of *Macrocystis*, and the economic potential of *Porphyra*. Our laboratory was open to visitors through the week-long meeting period. Also we had a number of

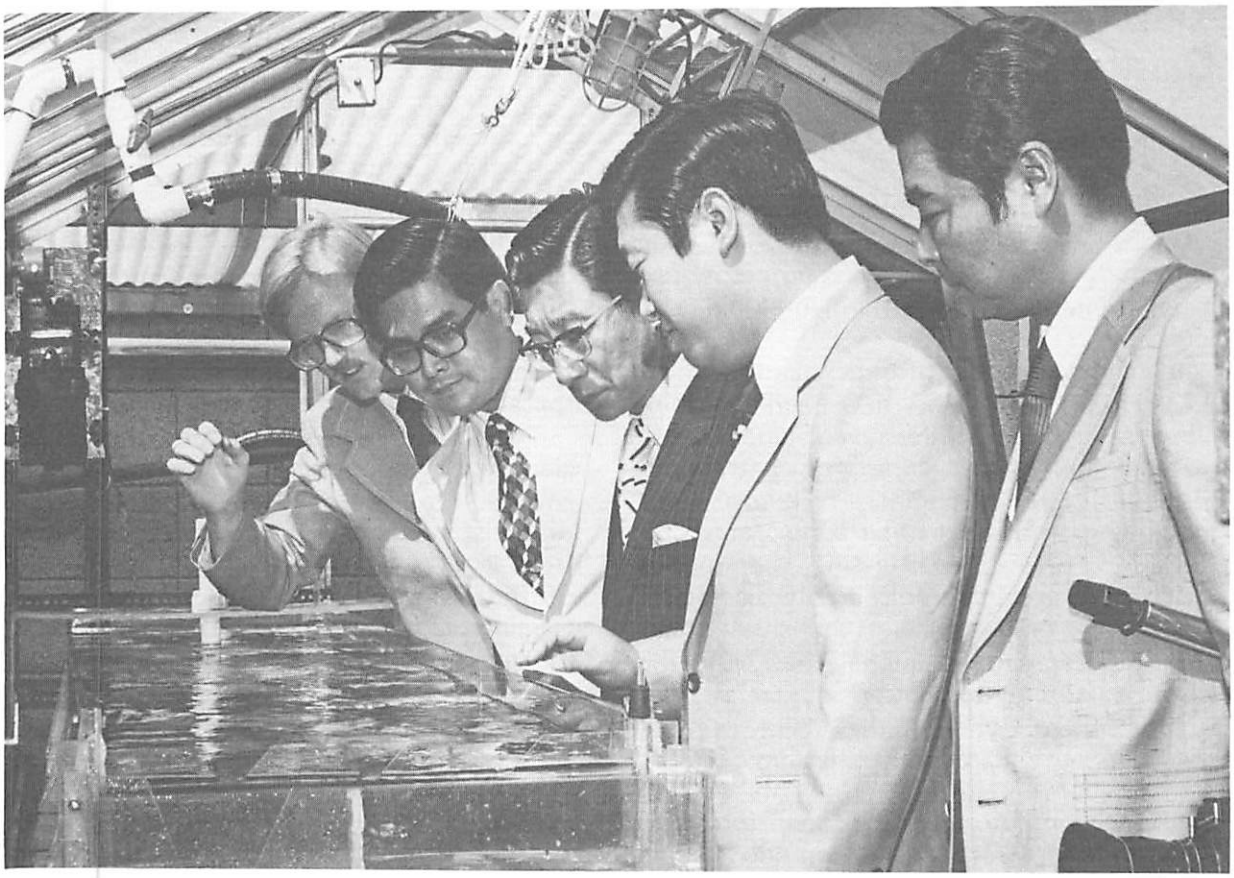

Fig. 2. DISTINGUISHED VISITORS – Phycologist James Woessner (far left) of the UCSB Marine Science Institute, who speaks Japanese, demonstrates the operations of the marine greenhouse where giant kelp is grown to Kenzo Muraoka (third from left), secretary to the director general of Japan's Administrative Management Agency, and three members of Japan's House of Representatives, Okiharu Yasuoka, Ichiro Ozawa and Koxo Watanabe. The visiting delegation, which included the head of Japan's Space Development Agency, Masafumi Miyazuwa, also were interested in oil spill prevention – Photo by Wildred Swalling

visitors to our laboratory both before and after the meetings (Fig. 2).

In summary, we can say with some satisfaction, that it has been a busy and productive year. We look forward to concluding this work in the coming year.

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Cooperating Organizations

Stauffer Chemical Company, Port Hueneme, California

Kelp Forest Ecology of the Central California Coast

John S. Pearse and Anson H. Hines

The high productivity and ecological complexity of kelp forests are being studied in this community approach to developing, managing and protecting the resources of these rich ecosystems. This study measures the standing crops, population dynamics, and trophic interactions of the major primary producers, herbivores and carnivores in kelp forests off the central California coast.

In our overall goal of understanding "how a kelp forest works," we have been determining the principal pathways of energy and material flow in kelp forests of central California. Through a community approach to developing and protecting kelp forest resources, we are investigating the species which have dominant roles in the ecological interactions of the system. Our study measures the seasonal and annual changes in the standing crops, population dynamics, and trophic interactions of the major primary producers, herbivores, suspension feeders and carnivores in the community. It is essential for sound management of kelp forests to have basic quantitative information on the populations which have primary roles in the productivity and ecology of these complex ecosystems.

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

We have concentrated our study on the kelp forest of the Hopkins Marine Life Refuge off Pacific Grove, California. This forest is within the established range of sea otters, which are particularly important predators regulating herbivore populations. During the second year of our three-year project, we have focused on major components of three trophic levels of the kelp forest: 1) quantification of the seasonal and annual changes in the giant kelp, *Macrocystis pyrifera*, the primary producer in the system; 2) measurement of the feeding rates and seasonal changes in the population densities, size structures, and standing crops of the major herbivores in the community (sea urchins, abalones, spider crabs, turban snails and bat stars); and 3) measurement of the diets and densities of certain major predators (sea stars, corals and sea otters) which regulate the herbivore populations and which partly structure the competition for substrate space on the floor of the kelp forest.

Two major causes of annual variations in giant kelp populations since 1974 have emerged from correlations of seasonal fluctuations in canopy surface area (computed from aerial photos provided by Mr. Dan Miller of the California Department of Fish and Game), plant density and size, and juvenile recruitment (Fig. 1). Large storms during the

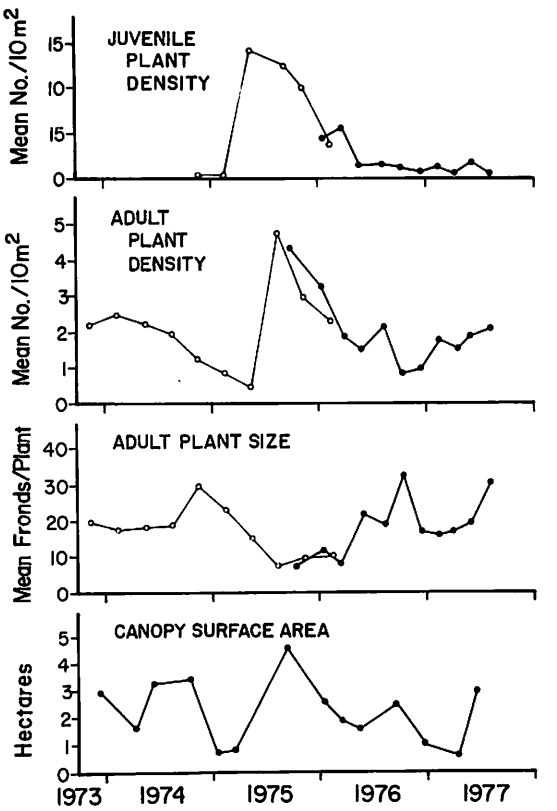

Fig. 1. Annual variations in populations of the giant kelp *Macrocystis pyrifera* at Hopkins Marine Life Refuge. Seasonal fluctuations in kelp had two major causes: 1) large storms in the fall of 1974 and a series of small storms in winter, 1975-76, and 2) a combination of unusually high sea temperatures with low nutrients in the summer of 1976, followed by heavy grazing in the fall. See text for further explanation

fall of 1974 tore out most of the giant kelp plants. This was followed by a heavy recruitment of juvenile plants which then thinned out as they grew into adults during 1975. The dense canopy was again thinned by small storms in the winter of 1975–76. However, during the following summer extremely stable hydrographic conditions produced a combination of high temperatures and low nutrients which apparently limited kelp growth. Subsequent heavy grazing by turban snails in the fall again reduced the canopy to a very low level. There were no major storms during this period, and plant densities remained constant, resulting in a rapid recovery of the canopy in the summer of 1977. Thus, storms in some years and combinations of high sea temperatures, low nutrients and grazing in others appear to account for annual variations in giant kelp populations. Densities and biomass of understory pea kelp *(Cystoseira osmundacea)* have remained constant during this period, while biomass of foliose red algae is greatest in the winter.

Completion of two years' study of the populations of the major herbivores in kelp forest shows that the densities of abalones and bat stars are constant through time; spider crab populations show repeated seasonal oscillations, while turban snails have long-period, non-seasonal fluctuations, and sea urchins undergo large, erratic fluctuations resulting from variable success in recruitment. Sea urchins, which have a high potential for overgrazing kelp and are important in the diet of sea otters, increased in density 500 per cent (to a density of about five per square meter) following a large successful settlement in 1975. After growing up to about 35 mm in diameter, the population has again dropped sharply in 1977 to a density of about two per square meter. This decline was apparently a result of predation by sea stars rather than by sea otters. From measurements of feeding rates and average densities of the major herbivores, we can estimate that approximately 20–35 per cent of the kelp produced in the system is consumed by these herbivores (see Table). Although turban snails and kelp crabs are grazing directly on attached kelp, most of the herbivores feed on drift algae, effectively cycling this resource within the food web of the kelp forest. However, grazing turban snails and kelp crabs often damage and weaken attached kelp, greatly increasing

Estimates of the consumption by the major herbivores in the Hopkins Marine Life Refuge of attached kelp plants and of attached kelp plants and of bottom drift kelp

	Mean Densities (per m^2)	Mean Feeding Rates On Kelp: Per Individual (gm/day)	Mean Feeding Rates On Kelp: Per Kelp Production (% at 63 gm/m^2/day)
On Attached Kelp			
Turban Snails	17	0.1	3
Kelp Crabs	0.1	5.4	1
On Bottom			
Turban Snails	50	0.1	8
Spider Crabs	5	0.1	1
Sea Urchins	2	2	6
Abalones	0.2	10	3
Bat Stars	4	2 (Held)	13
			35%

production of drift kelp to the bottom.

Our initial studies show that predatory sea stars, anthozoans, fish and sea otters have a broad and diverse food base on the major herbivores and bottom-encrusting invertebrates in the Hopkins Marine Life Refuge. Preliminary estimates of the impact of sea otters feeding in the system indicate that these predators are playing a major role in regulating the herbivore populations. In a study funded by the Marine Mammal Commission, Mr. Daniel Costa at UC-Santa Cruz has measurements of the metabolic requirements, diet and caloric values of food items of sea otters foraging in our study area. These data show that the herbivores we are studying make up nearly 100 per cent of the diet of sea otters; and they allow us to extrapolate from our density measurements that, for example, as much as twice the size of the existing kelp crab and 30 per cent of the abalone population standing crops are consumed by otters each year. The doctoral research of Sea Grant trainees Christopher Harrold on sea stars, and Yusef Fadlallah on corals, indicates that these animals play an important role in structuring the "turf" on the bottom of the kelp forest. The stars remove patches, and corals affect larval settlement of encrusting invertebrates which compete with algae for substrate. Sea stars also forage on turban snails and sea urchins.

Point Santa Cruz: A kelp forest recently included in the range of sea otters

Seasonal monitoring of four permanent stations in the kelp forest off Point Santa Cruz, Santa Cruz County, has shown that until the winter of 1975–76 the seaward por-

tion of the forest was dominated by large numbers of sea urchins and was relatively barren of algae. Aerial photographs provided by the California Department of Fish and Game indicate that the forest boundaries were quite stable for the previous five years. During the spring of 1976 a major, though localized, mass mortality of red sea urchins destroyed the population of these grazers in all but a narrow band along the edge of the kelp forest. Caused by an unknown sea urchin disease, this mass mortality has been followed by the subsequent seaward enlargement of the kelp forest by more than 10 hectares (Fig. 2). The northward expanding front of sea otters has recently reached the Santa Cruz kelp forests; and in the winter of 1976-77 several sea otters were often seen in kelp forests off Point Santa Cruz. These animals have now consumed most of the few remaining sea urchins in the area as well as numbers of abalones, crabs and clams. The observed sea urchin mass mortality provides independent documentation that removal of large numbers of these grazers has dramatic effects on the structure and production of kelp forests.

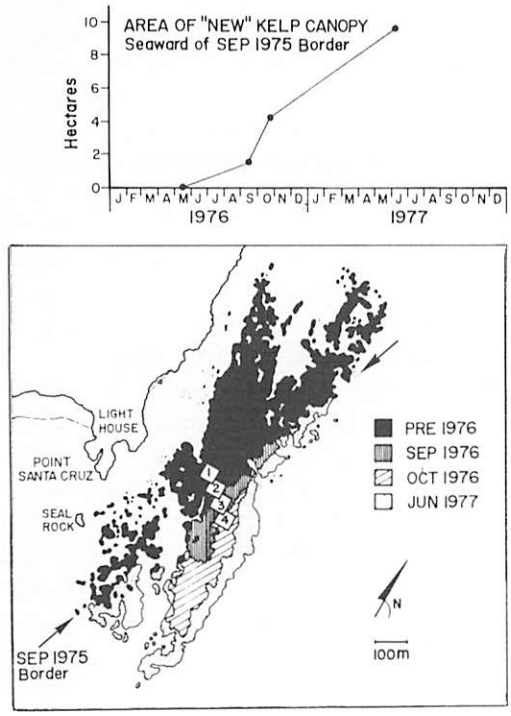

Fig. 2. Map of the canopy of the kelp forest off Point Santa Cruz showing the stable border before the winter of 1975, and the area of the seaward expansion of the forest following the mass mortality of the red sea urchins in the spring of 1976

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Papers presented at meetings

Agegian, C., M. Yellin, and J. S. Pearse, Ecological benchmarks in the Santa Cruz County kelp forests before the re-establishment of sea otters. 57th Annual Meeting of the Western Society of Naturalists, California State University, Fullerton, 1976.

Gerard, V. A., The standing crop, turnover and ecological significance of benthic drift algae and sea grasses in a central California kelp forest. IXth International Seaweed Symposium, Santa Barbara, California, 1977.

Harrold, C., Changes in the diet of *Pisaster gigantens* resulting from damage inflicted by sea otters. 57th Annual Meeting of the Western Society of Naturalists, California State University, Fullerton, 1976.

Hines, A. H., Habitat partitioning, densities, population structures, reproduction and growth in five species of spider crabs in a central California kelp forest. 57th Annual Meeting of the Western Society of Naturalists, California State University, Fullerton, 1976.

Pearse, J. S., and A. H. Hines, A localized die-off of sea urchins off Santa Cruz, California, and its consequences on kelp production. 57th Annual Meeting of the Western Society of Naturalists, California State University, Fullerton, 1976.

Idem, Ecological studies in a kelp forest inhabited by sea otters. IXth International Seaweed Symposium, Santa Barbara, California, 1977.

Idem, The expansion of a kelp forest following mass mortality of a localized population of sea urchins. IXth International Seaweed Symposium, Santa Barbara, California, 1977.

Carrageenophyte Cultivation, Genetics, Population Dynamics, and Development of Agar Substitutes

W. Doyle, J. West, and I. Abbott

This intercampus project is concerned with the improved cultivation of *Iridaea cordata* and *Gigartina* for enhancement of carrageenan production, and the development of carrageenans as agar substitutes.

IRIDAEA POPULATION DYNAMICS AND CULTIVATION – Research at Santa Cruz

The red seaweed *Iridaea cordata* is from a family of plants known to produce carrageenans. These phycocolloids are used as gelling, thickening, and stabilizing agents by numerous industries (food, biomedical, pharmaceutical, cosmetic, and textile). The overall goal of this program is to assess the feasibility of a Pacific coast seaweed fishery for the production of *Iridaea* carrageenan. With previous Sea Grant support we studied *Iridaea* carrageenan biochemistry (McCandless, *et al.*, 1975), population biology (Hansen and Doyle, 1976; Hansen, in press), growth (Hansen, 1977) and aspects of physiology (Hansen, 1977). During the 1976-77 grant year we have concentrated on *Iridaea* cultivation and on aspects of physiology which relate to improvements in cultivation.

Aquaculture/field cultivation

A nearshore experimental aquaculture system has been developed for *Iridaea* employing nets as artificial substrate (Fig. 1). The original system was destroyed by a ship propeller; subsequently, new systems have been constructed. The moorings rest on a sandy substratum at -5 m depth off Pacific Grove, California. Techniques for sporulating nets in tanks have been worked out; currently nets are attached (at -1.5 m depth) to the moorings, and growth experiments are in progress.

Field cultivation studies included measurements of blade production and growth in a natural population (Fig. 2). The results demonstrate that juvenile blades are inhibited by the large, dominant blades, and that this is not a shading effect.

Selective harvesting of these large blades can result in two crops per growing season, but timing is critical. Tagging studies showed that growth potential in some plants is consistently very high, encouraging the idea of strain selection for aquaculture purposes.

Laboratory studies

The irradiance level and nitrogen source for best *Iridaea* growth were determined by measuring physiological responses of field-collected plants. Photosynthesis is saturated between 150-200 μE (similar to the irradiance reaching the floor of a dense redwood forest). Productivity of immature blades is nearly twice that of reproductive blades (Fig. 3). This suggests that the most efficient harvest should take place just as the blades mature. Productivity is light-limited during

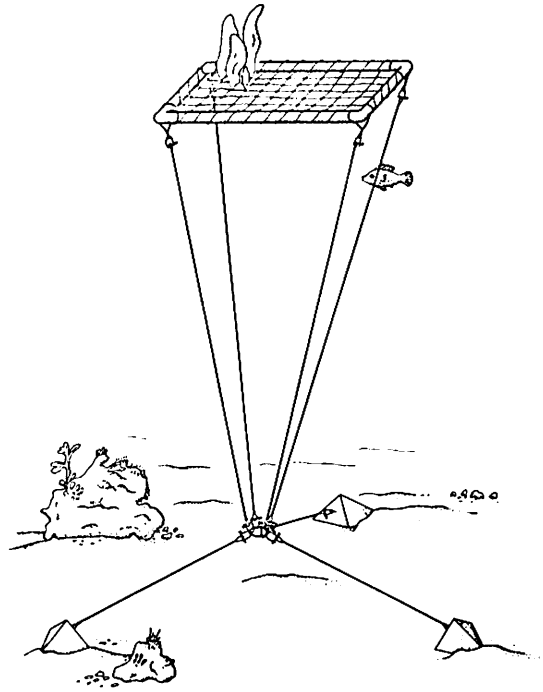


Fig. 1. Experimental aquaculture system for *Iridaea*, showing net as artificial substrate

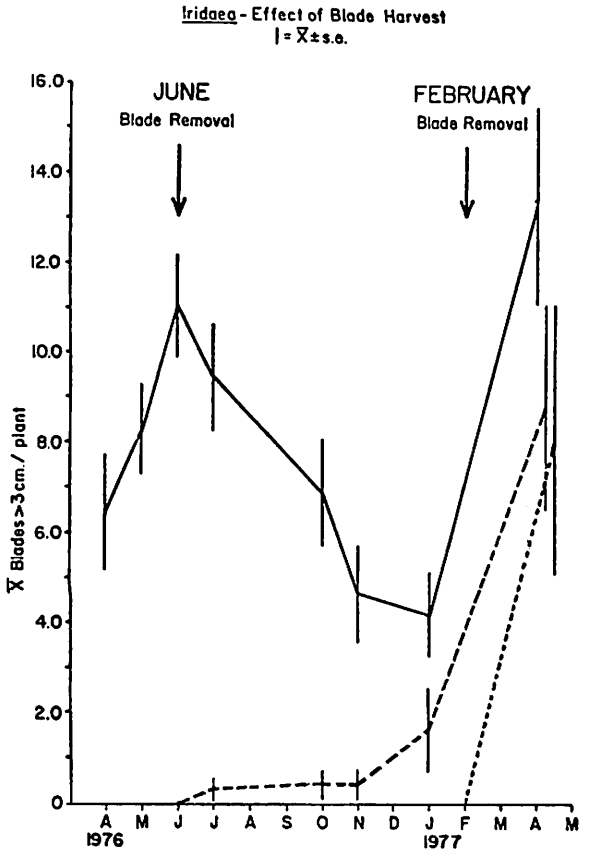


Fig. 2. Effect of harvest on subsequent blade production by *Iridaea cordata* holdfasts. _____Control, _ _ _ _ Blade growth following removal of all blades >3 cm in length in June and February. Harvest in June resulted in no subsequent growth on the holdfasts until the following spring. Harvest in February resulted in growth of a new crop of blades to control levels within two months, allowing another more major harvest in the summer months. Thus, harvest of two crops per growing season is possible, but timing is critical

winter, indicating that growth could be enhanced by manipulating this factor. Ammonium is the preferred nitrogen source for this species, and productivity could be enhanced by a fertilization regime.

The *Iridaea* polysaccharide carrageenan, extracted and processed for industrial use, is of two types: viscous and gelling. Crops from *in situ* California populations produce primarily viscous (lambda) carrageenan because the populations are dominated by diploid plants. Gelling (kappa) carrageenan, the type most highly prized by industry, is a product of male and female plants only. Therefore, gelling carrageenan could only be produced in quantity through aquaculture procedures; specifically net culture of male and female plants.

Collaboration/advisory service

Our progress in this program has been substantially enhanced by cooperation and technical assistance from: Prof. I. A. Abbott (Stanford University), Prof. M. S. Doty (University of Hawaii), Prof. E. L. McCandless (McMaster University), Prof. J. S. Craigie (Atlantic Regional Research Laboratory), Dr. T. Mumford (Washington State Department of Natural Resources), and the Soil Control Laboratory (Watsonville, California).

The resultant program achievements have allowed us to offer both scientific and technical advice to Marine Colloids, Ltd., Stauffer Chemical Co., Washington Department of Natural Resources, and Catalina Offshore Products. Also, results from this project were recently presented (Hansen; Packard) to a diverse audience of industrialists at the 9th International Seaweed Symposium, Santa Barbara (1977). Further information from this project has been supplied to the proceedings – Marine Biomass of the Pacific Northwest [W. Krauss, (Ed.), 1977].

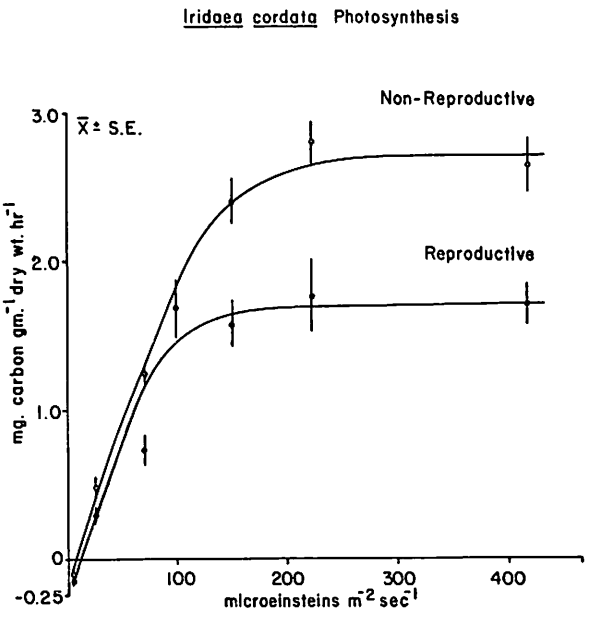


Fig. 3. Photosynthetic rate of non-reproductive and reproductive plants with mean values ± the standard error

A GENETIC PROGRAM FOR IMPROVEMENT OF CARRAGEENAN PRODUCTION IN THE RED ALGA *GIGARTINA* — Research at Berkeley

The marine red alga *Gigartina* is potentially a major source of the phycocolloid carrageenan which is widely used in commercial food products and in other industries. Genetic selection of strains with higher yield and superior quality carrageenans appears probable through controlled laboratory breeding. During the past two years, with Sea Grant support, we have initiated a program to test this idea. Individual plants were selected and marked in the field and were sampled at 2-4 month intervals for a year. Analyses were done on each plant to determine seasonal variation in carrageenan yields and types. Each plant was also sampled to determine its reproductive status (male, female — sexual or apomictic). During the past year the following activities were undertaken.

Carrageenan determinations

Although our data are based on a necessarily small sample size (0.5-1.0 g dry weight/plant) because we are assessing seasonal variation of individual plants of our genetic stocks, the within sample error is low [less than 5 per cent for sulfate and less than 7 per cent for 3,6-anhydrogalactose (3,6-AG)]. Because of the small sample size, we were unable to prepare kappa (κ) and lambda (λ) fractions reliably. Several generalizations can be made from data thus far accumulated for *Gigartina papillata*.

1. A. Percentage yield of carrageenan varies overall from 40 to 70. The mean yield is 57 per cent. Individual plants exhibit as much as a 15-20 per cent range seasonally.
   B. Percentage of 3,6-AG ranges from 14.2 to 19.0 — mean 17.0
   C. Percentage of SO_4^{-2} is 15.4 to 30.1 — mean 25.1.
2. No significant differences exist in the percentage yield and percentages of SO_4^{-2} and 3,6-AG between male and female plants.
3. There is no positive correlation between low percentage 3,6-AG and high percentage SO_4^{-2} in samples tested thus far.
4. Values for 3,6-AG are lower and SO_4^{-2} are higher in *Gigartina papillata* than in *Chondrus* and *Iridaea.*
5. There is no significant difference between apomictic and sexual plants of *G. papillata* with respect to percentage yield, and percentages of 3,6-AG and SO_4^{-2} (based on a limited sample of two apomictic and four sexual plants).
6. Within any single plant there is significant seasonal variation in percentage yield, and percentages of 3,6-AG and SO_4^{-2}.

These data and our interpretation, although still preliminary because of certain analytical limitations, indicate that there is a significant variation in the yields and types of carrageenan in contrast to other data reported for seasonal variation in pooled gametophytic plants of *Chondrus* and *Iridaea.* It is apparent that further information is necessary on the molecular structure obtained through infrared and nuclear magnetic resonance spectroscopy, as well as immunochemistry, before the exact genetically based nature of various carrageenans present in these plants can be determined.

Hybridization experiments

The breeding studies between selected parental types of our genetic stocks are continuing. Tetrasporophytes derived from the first crosses are still immature. Utilizing the additional carrageenan data on percentage sulfate and percentage of 3,6-AG, we have selected and crossed additional promising parent types.

In addition, we have initiated crossing experiments to determine genetic affinities between *Gigartina pacifica, G. ochotensis* from Japan and *G. pacifica* and *G. papillata* from Pacific North America. Preliminary results indicate a very low genetic similarity. Only two of 30 have crossed and these exhibit substantially impaired fertility, lower percentage fertilization, slower development of carposporophytes and low numbers of carpospores released relative to self-cross controls. Crosses have been attempted between *G. stellata* (North Atlantic) and *G. papillata* (North Pacific), but all crosses are negative as might be anticipated if one considers the geographical isolation of these species.

SAMPLE DATA FOR *GIGARTINA PAPILLATA* GENETIC STOCKS

Plant No.	Sex	Collection Date	% Yield Carrageenan	% 3,6-AG	% SO_4^{-2}	Maximum Percentage Growth Increase/Month
15G	♀	I-15-76	62	19.5 (4)	23.0	
15G		II-26-76	57	15.2	28.3	0
15G		V-16-76	60	17.1	28.7	+ 4
15G		XI-20-76	70	20.6	26.0	+23
29C	♀	X-18-75	69	18.9	15.4	
29C		I-15-76	61	18.2	22.9	-17
29C		III-20-76	60	17.7	25.0	+28
29C		V-15-76	53	17.6	26.7	- 8
29C		VI-14-76	53	5.7	26.5	+27
29C		IX-23-76	66	8.6	22.7	- 5
32D	♀ (apomictic)	X-18-75	57	16.0	24.5	
32D		I-15-76	46	16.2 (4)	24.7	-15
32D		V-15-76	53	14.8	26.5	+22
32D		VI-14-76	58	16.5	26.9	-14
32D		IX-23-76	51	16.5	24.5	+ 8
34A	♂	VI-14-76	58	18.3 (4)	26.4	
34A		IX-23-76	61	18.1	24.9	+36

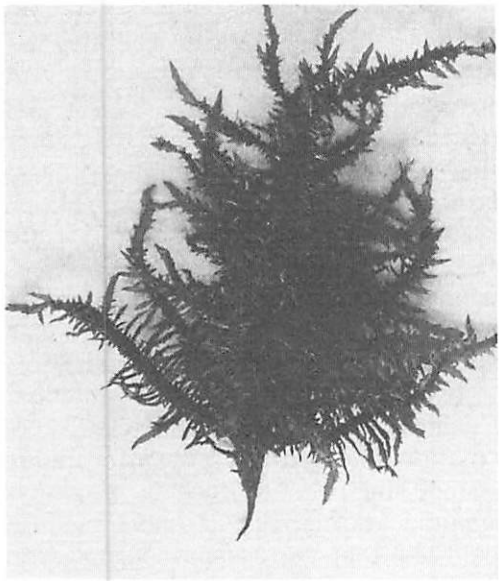
Induction of tetrasporogenesis

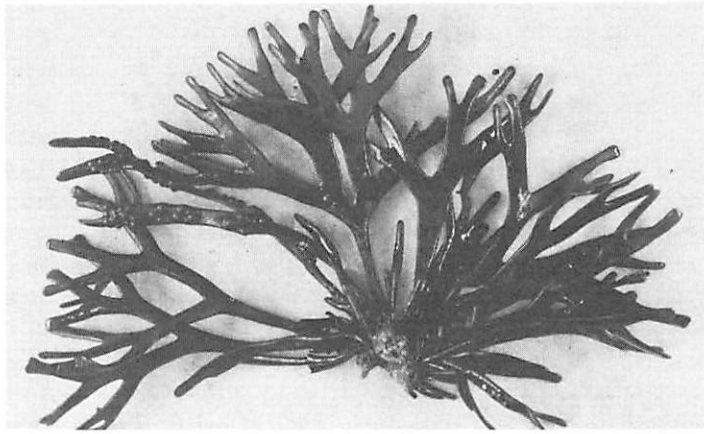
Further experiments have been started this year to determine the environmental requirements to induce sporulation in the F_1 hybrids derived from the crossing experiments. Short-day conditions (8:16 light/dark) at either 10 or 15°C induced sporulation in about 30 per cent of those tested so far.

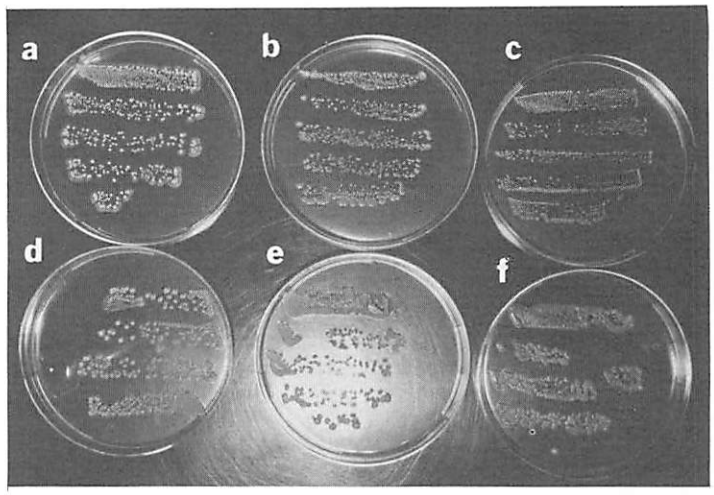
Additional studies

Because information on the life history patterns is essential for genetic studies, we have also continued our culture investigations on this subject. During the past 18 months we have expanded our investigations on life histories and genetics of the genus *Gigartina* and *Petrocelis* to include other geographical areas and species. Carrageenan analyses on the cultured stocks and field-collected specimens have not been undertaken yet, but we have substantial data to report on other aspects of their biology. One strain of *Gigartina johnstonii* obtained from Punta Peñasco, Sonora, Mexico is growing well in culture. The sexual life cycle is completed in less than eight months under conditions tested. Apomixis was not observed. Growth is remarkably rapid throughout development, the plants generally reaching a length of 2.5 cm in four months when reproduction occurs. Reproductive plants continue to grow vigorously to a total length of 5 cm. *G. johnstonii* appears to be closely related to *G. pectinata*, *G. teedii* and *G. tepida*, and we plan to do comparative culture studies on these species as well. Currently we have *G. teedii* from England in culture but have not completed the life cycle.

These species show potential for carrageenan weed culture because of their wide geographical distribution and rapid growth.







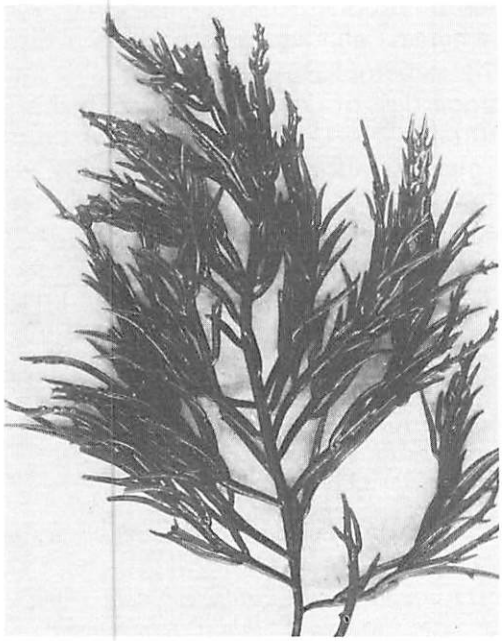


Fig. 4. (Clockwise, from upper left). *Gigartina leptorhynchos*; *Gymnogongrus linearis*; bacteriological plates using agar (a & b) kappa carrageenan (c), iota carrageenan (d & e), and ahnfeltan (f), as the colloid; *Rhodoglossum affine*; and *Neoagardhiella baileyi*

G. teedii is harvested from natural populations in southern Europe.

Gigartina stellata is used extensively in Europe as a commercial source of carrageenan. Our studies on *G. stellata* and its alternate phase (tetrasporophyte), previously known as *Petrocelis cruenta*, involved extensive collecting and culturing of plants from several countries in the N. Atlantic – France, Portugal, Iceland, Scotland, England, Ireland, Wales, and Maine in the U.S.A. The life cycle patterns have been analyzed for these isolates and show a striking similarity to those observed in the northeastern Pacific with *G. papillata* and *G. agardhii.* Northern populations of *G. stellata* are predominantly apomictic, whereas southern populations are largely sexual: Iceland (3 of 3 apomictic), Ireland (2 of 3 apomictic), Scotland (3 of 3 apomictic), Wales (11 of 11 apomictic), England (7 of 10 apomictic), France (1 of 5 apomictic), Portugal (0 of 9 apomictic). We are carrying out hybridization experiments with isolates obtained in England, France, Ireland and Portugal. Viable crosses have resulted between plants collected as far apart as Ireland and Portugal, indicating close genetic proximity among the Atlantic populations. We are obtaining additional isolates from Spain and Denmark for comparative work.

DEVELOPMENT OF AGAR SUBSTITUTES – Research at Stanford

Field studies on 16 species of marine red algae in central California have shown a seasonal variation in abundance of some species and a constant availability in other species. A comparison of ratios demonstrates seasonal variation of wet and dry weights in some species. These data make it possible to know the best times for harvest with respect to the potential yield of carrageenan, an important colloid used principally in food and drug manufacture. Laboratory tests show that nine species produce kappa-carrageenan, three produce iota-carrageenan, two produce agar, and two, other colloids. Of the kappa producers, all yield the colloid in quantities greater than 50 per cent of dry weight.

The most important contribution of this study is the demonstration that kappa-carrageenan, from whatever seaweed source and whatever prior chemical treatment, is suitable for general microbiological use. In most cases, kappa-carrageenan has two advantages over agar in culture media: it goes into solution at a significantly lower temperature (roughly 30–40°C lower), and sets or gels at a lower temperature. The lower dissolving temperature speeds media preparation and reduces the possibility of high-temperature decomposition of media. Microbiologists believe that a variety of microorganisms not easily cultured on agar may be cultured in the cooler gelling kappa media, particularly in those cases where the organisms must be combined with the medium before gelling. The slower and cooler kappa gel formation adds to the ease of handling and reduces the need to rush in dispensing the medium. Additionally, it had previously been believed that carrageenan forms droplets of water (syneresis) in petri dishes as does agar. Repeated testing in this study has shown that syneresis is rare when using kappa-carrageenan, whereas this is a regular phenomenon on an agar plate. This lack of syneresis could save many hours used in waiting for the moisture in the agar plates first to condense and subsequently to evaporate.

Two species of algae that produce iota-carrageenan show that both gametophyte and sporophyte plants may be used in extraction, whereas all kappa producers utilize only the gametophytes for this colloid. Certain properties of iota-carrageenan make it less suitable for general microbiological work: media made with iota are highly viscous, have a very fast cool-down time, and have a rubbery surface that is difficult to streak. However, iota-carrageenan produces a softer gel, potentially more suitable for phage culture than the gel formed by the firmer kappa-carrageenan and currently used agar.

Publications

W. Doyle:

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J. West:

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Idem, Golgi apparatus of unique morphology during early carposporogenesis in a red alga, *J. Ultrastruct. Res.*, **58**, 119-133 (1977).

Cooperating Organizations

Atlantic Regional Research Laboratory, Nova Scotia, Canada

Marine Colloids, Inc., Rockland, Maine

McMaster University, Ontario, Canada

NATO, Scientific Affairs Division, Bruxelles, Belgium

Portsmouth Polytechnic Marine Lab, Hayling Island, England

Soil Control Laboratory, Watsonville, California

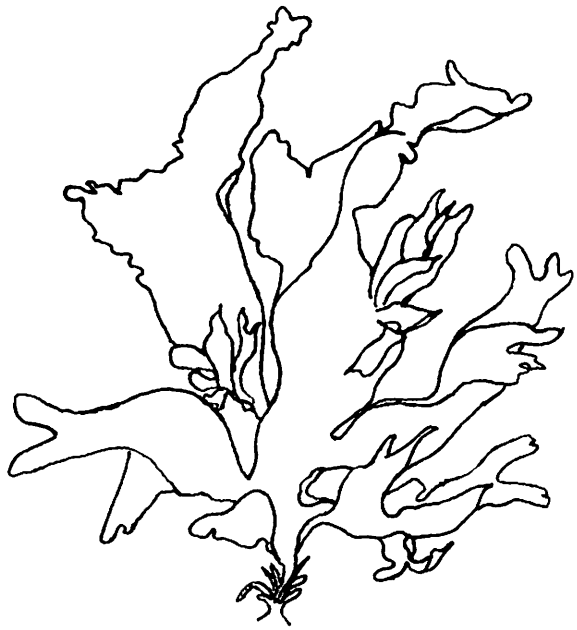
Stanford University, Department of Microbiology, Stanford, California

University of California Irvine, Department of Ecological and Environmental Biology, Irvine, California

University of California Santa Cruz, Department of Natural Sciences and Department of Chemistry, Santa Cruz, California

University of Hawaii, Department of Biology, Honolulu, Hawaii

Washington State Department of Natural Resources, Olympia, Washington



Toward Seawater-Based Crop Production

Emanuel Epstein

Barley selected for salt tolerance and grown successfully under irrigation with undiluted seawater was found to be of good feed quality. In a second trial, the top yield of the best selection approached the average world yield for barley. Gratifying progress has been made in adapting wheat and tomatoes to seawater culture.

The year 1976-77 marked the "coming of age" of a program that was begun with high hopes but no assurance of success. The expectations entertained at the initiation of this project are being realized for barley, and indications are favorable for success with wheat and tomatoes as well. Barley has in two successive seasons been grown in the sand dunes at Bodega Marine Laboratory, being irrigated throughout its life cycle with undiluted seawater which supplies mineral nutrients as well as water. Work with wheat and tomatoes was started later and is inherently more difficult, but progress with these species is also satisfactory. The results seem to bear out the validity of the premise which lies at the foundation of this enterprise — that given an adequately large reservoir of genetic variability, it is possible to select and breed crops suited to highly saline conditions including brackish water and seawater culture.

Barley

Barley grain harvested from the first field trial at Bodega Marine Laboratory was analyzed for feed quality by chemical tests and found to be satisfactory. Irrigation with undiluted seawater caused no unfavorable changes in the chief quality factors, which are the content of protein, fat, nitrogen-free extract (essentially carbohydrate), and fiber. The sodium content was doubled under seawater culture, but even this increased value (0.3 per cent) is so low as to pose no problems. A laboratory test for digestibility was also satisfactory. Eventually it will be necessary to conduct actual feeding trials, once adequate amounts of seawater-grown grain become available. Present facilities are inadequate for such large-scale tests.

In a second field test at Bodega Marine Laboratory conducted in the 1976-77 season, one genetic line of barley gave a higher yield than the top yields achieved before in seawater culture, approaching the average world yield of barley (estimated for 1975 to have been 1710 kilogram per hectare, or 1527 lb per acre). It is concluded that with continued selection and a breeding program, yields of barley grown in seawater culture can be increased to values well beyond the world average. Further selection work has already been initiated. It draws on the 22,000 genetic lines contained in the world collection of barley — a huge reservoir of genetic variability.

Tomato

The commercial tomato "Walters" was found to be exceptionally vigorous and possibly more salt-tolerant than the commercial line used in the beginning of this work, "VF 36." "Walters" was crossed with the wild, salt-tolerant but commercially useless tomato, *Lycopersicon cheesmanii* (see previous Annual Reports). Progeny from this cross bears tomatoes about the size of cherry tomatoes and tolerates approximately 60 per cent seawater salinity, or 21,000 ppm. Yield data for this trial are not yet available, but indications are that yields will be appreciable. Research has also been done on physiological and biochemical differences between the salt-sensitive commercial tomato and the salt-tolerant wild one. It is hoped that these investigations may lead to the discovery of physiological or biochemical 'markers' for salt tolerance. If such markers could be found, they would aid in the early identification of salt-tolerant genetic lines and thus speed up the work of selection and breeding. So far, however, no reliable markers have been found. For the time being, reliance must be placed on the conventional criteria of growth, yield, and quality.

Wheat

The world collection of wheat genetic lines is being screened for salt tolerance, using the same large salinized solution culture set-ups that were found satisfactory for the selection

A lone wheat plant survives and produces grain on a tank containing nutrient solution salinized to 50 per cent seawater salinity. The seeds of these plants were all subjected to this salinity from the beginning of the experiment; most of the plants succumbed as shown. Seed from the successful plant will be increased for further selection and breeding

of salt-tolerant lines of barley. Wheat does not have the reputation that barley has as a fairly salt-tolerant crop. Nevertheless, several hundred genetic lines of wheat have already been identified whose seeds can germinate and establish seedlings at 85 per cent seawater salinity. Their seed was increased and tests are now under way to establish whether the plants are tolerant at later stages of their life cycle, including flowering and seed set (grain production).

Publication of a paper on the first field test of barley grown in seawater culture in the dunes at Bodega Marine Laboratory (*Science*, July 15, 1977) caused worldwide interest. Newspapers, magazines, and radio and TV stations have given wide recognition to this research, and interest in it seems to continue. The Wall Street Journal, the New York Times, the China Post (Taiwan), *New Scientist* (London), Business Week, and Columbia Broadcasting System are just a few of the media that carried stories or interviews. There also has been a veritable avalanche of inquiries from government ministries, departments of science and technology, research institutes and scientific information services from all over the world.

Publications

Epstein, E., Genetic adaptation of crops to salinity. Proceedings of the Workshop on Salt Effects on Plant Structures and Processes, Riverside, California, April 26-28, 1976. Agricultural Research Service, U.S. Department of Agriculture, pp. 51-53, Publ. December, 1976.

Epstein, E., and J. D. Norlyn, Seawater-based crop production: a feasibility study, *Science*, **197**, 249-251 (1977).

Rush, D. W., J. D. Norlyn, and E. Epstein, Salt-resistant crops coming, *Crops and Soils*, **29** (3), 7-9 (1976)

Cooperating Organizations

Bodega Marine Laboratory, Bodega Bay, California.

Departments of Agronomy and Range Science, Vegetable Crops, and Genetics, University of California, Davis.

U.S. Department of Agriculture, several locations.

Effects of Public Regulation on California's Aquaculture Industry

Gerald Bowden

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

This project is essentially an inquiry into the question whether California's coastal aquaculture industry is as overregulated as industry spokesmen state it to be. Work on this question has focused on three topics. First, we have conducted detailed research into the substantive law governing coastal aquaculture. The product of this research is a draft document which is currently under review by public agencies and private aquaculture operators. Second, an extensive analysis of the competing public policies embodied in the law has been begun. These policies run the gamut from consumer protection to economic development. The purpose of this analysis is to determine whether some policies, such as those designed to protect environmental quality, dominate or even foreclose other public policy objectives, such as the stimulation of new economic activity. Third, an attempt has been made to determine whether public regulation plays an important part in the growth of an aquaculture industry in California. The results of this inquiry are not yet complete.

Survey of operating techniques

In pursuing these three objectives over the past year it has been necessary to become acquainted with the operating techniques used by aquaculturists along the coast. In order to gain this knowledge, many of these growers were interviewed. It was also necessary to interview a large number of the public officials responsible for administering regulatory programs. On the basis of these interviews, a draft document has been prepared suggesting a few remedial changes in existing law. This document will be refined in the coming year and incorporated in the final report of this project. We have also begun an analysis of the economic costs of public regulation to the aquaculture industry. This analysis will be included in the final report.

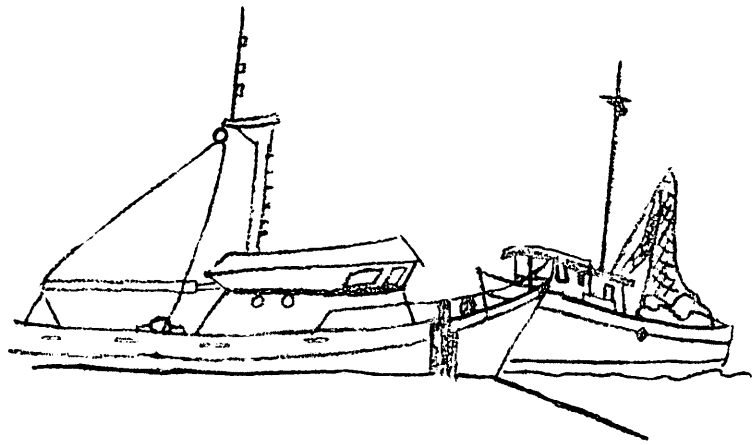
In short, the purpose of this project is to gain a better understanding of the law governing coastal aquaculture in California and to assess the effect these laws have on its growth. One hopes that this understanding will better equip us to evaluate the overall utility of the legal fabric within which this industry must function.

Cooperating Organizations

Numerous public agencies have furnished advice and assistance. They include representatives from the following:

State: Attorney General's Office, Coastal Commission, Fish and Game, Lands Commission, Legislative Committee staff, Public Health.

Federal: Army Corps of Engineers, EPA, NMFS, and NOAA.



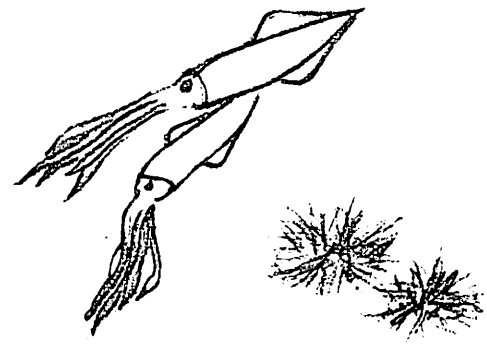
FISHERIES

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

After combining the sea urchin fishery projects at UC-Santa Barbara and Scripps Institution of Oceanography, this intercampus study continues to investigate the parameters governing sea urchin population necessary for managing this large fishery in a sustained-yield manner consistent with the optimal use of kelp community resources.

The UC-Davis projects to develop new antioxidants for the prevention of deterioration of fish lipids which depreciate the value of preserved fish and to investigate the natural fermentation of marine products have been completed. Better handling methods have been devised. It was found that fresh fish stored in atmospheres containing elevated levels of carbon dioxide were maintained in better condition than controls stored in air, which should lead to longer shelf life. A further group of projects are concerned with finding the cause of scombroid poisoning.

In view of the fact that this country and an increasing number of others are in the process of establishing 200-mile fisheries zones along their shores, social scientists are exploring the social, political and economic consequences of this and other management innovations on fisheries, in particular the abalone industry.



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

Theodore H. Kerstetter

Survival of anadromous fish in the ocean is subject to a number of variables, not the least of which may be disease. Vibriosis, caused by the marine bacterium *Vibrio anguillarum*, can infect Seaward migrants at any time after their arrival at river estuaries. This disease has caused mortalities as high as 90 per cent in salmon pen-rearing experiments in marine water. A fresh water disease, furunculosis, takes a heavy toll in some hatcheries and can continue as an important cause of death well after infected stocks enter the sea.

Immunization of fish against vibriosis by immersion in a vaccine broth has for the first time created the potential for anadromous fish hatcheries to routinely protect all young fish destined for ocean life against this disease. This project, carried out in collaboration with Tavolek Laboratories, Redmond, Washington, and the California Department of Fish and Game, is the first large-scale field test of immersion immunization south of the Columbia River. It should provide one of the first indications of whether routine vibriosis immunization can effectively increase the yields of salmon and steelhead trout from west coast hatcheries. In the first year of this 2-year program, efforts were concentrated on coho salmon and steelhead trout at the California Fish and Game Mad River Hatchery, near Arcata.

In a three-week period from late December through early January, 88,000 yearling coho salmon were marked with coded magnetic wire nose tags, and their adipose fins were clipped to identify them as tagged fish. Two different codes were used, one signifying immunized fish and the other non-immunized controls. Forty-three thousand of the young salmon, all appropriately marked, were immunized February 15, 1977. Two weeks later the young salmon were released to begin their 10-mile migration down the Mad River to the ocean. A cooperative tag recovery and decoding program among the Pacific Coast states will provide information indicating whether or not immunized coho salmon are caught in greater numbers in the commercial fishery. Reproductively mature salmon, returning to the hatchery in the fall of 1978, will be a further source of information on the effect of immunization on survival.

On February 16, 33,800 yearling steelhead trout were immersion-immunized against vibriosis. One week later, they were given an identifying mark by fin clipping, together with a group of 26,200 (with a different mark) to act as controls. Coded tags were not used with steelhead, since this species is not taken in the ocean fishery in significant numbers.

To get an immediate indication of the success of the immunization procedures, the degree of protection against vibriosis was assessed by exposing fish to known concentrations of the bacteria for a carefully timed period, usually 20 minutes. In this procedure, bacterial concentrations are adjusted to a level that will cause about 50 per cent mortality in non-protected fish. One group of 88 immunized salmon, air-freighted to Tavolek Laboratories for challenging, showed a 100 per cent survival, while 32 per cent of the 97 fish in the control group died. At the Humboldt State University Marine Laboratory, young salmon and steelhead were challenged with *Vibrio* exposure and immediately put into seawater tanks. In two experiments, immunized salmon showed 100 and 96 per cent survival, while controls had cumulative survivals of 10 and 56 per cent, respectively. Among steelhead trout tested, 61 per cent of the immunized survived vs. 6 per cent of the controls. In tests for serum antibodies four weeks after immunization, immunized fish showed strong agglutination for *Vibrio anguillarum*, while controls were negative.

Transfer of immunity

Another aspect of the project was the successful transfer of vibriosis protection to non-immunized fish by injecting lymphocytes

isolated from immunized fish. This work (now about 80 per cent completed) was done in order to learn whether cell-mediated immunity, blood-borne antibodies, or a combination of both is responsible for the transfer of protection. The information is necessary for a thorough understanding of immune systems in fish, and in a more immediate sense it will tell us whether the first stage of immunity after vaccination results from blood-borne antibodies alone and is thus susceptible to detection by standard blood testing methods. The tissues from which competent (capable of protecting against disease) lymphocytes are taken, the time interval after vaccination before they become competent, and the presence or absence of circulating antibodies in protected fish, both donor and recipient, are all potential clues to the nature of the transferred protection.

Protection was assessed by the methods described above for challenging fish to vibriosis. Tissues used as a source of lymphocytes for transfer were spleen, thymus, anterior kidney, and blood. In this procedure, the lymphocytes are suspended in a cell culture solution after collection, counted, and tested for viability. They are then injected into non-immunized fish.

Fish receiving lymphocyte injections are exposed to *Vibrio* bacteria within a few hours, and mortalities are counted for six days thereafter. The effectiveness of disease protection is directly related to the percentage of the recipient group surviving.

Eight cell transfer experiments have been completed to date, using donors at 11(2), 12, 20, 21, 23(2), and 29 days post-vaccination. Protection was successfully accomplished with anterior kidney and peripheral blood lymphocytes, and with cell-free serum. While 29-day donors yielded the greatest degree of protection, some immunity was evident in recipients of 20-day post-vaccination lymphocytes. Still to be done are the assays for the presence of blood-borne antibody in the lymphocyte recipients, and additional transfer experiments at post-vaccination times in excess of 30 days.

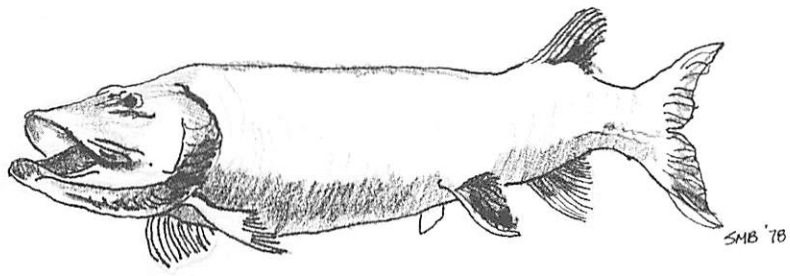
Work remaining

In the second year of the project, 90-day old chinook salmon will be marked and immunized in procedures such as those used with coho. The first returns of marked fish should occur in 1978, and although returns will continue through 1982, trends may be apparent as early as the winter of 1979.

Cooperating Organizations

California Department of Fish and Game, Sacramento, California

Tavolek Laboratories, Inc., Redmond, Washington



The California Market Squid Fishery

Conrad W. Recksiek

Moss Landing
Marine Laboratories
R/F-15

The third year of this four-year research program on the biology of market squid has been devoted to accumulating additional data on reproductive and population biology, predator-prey relations, spatial-temporal distribution, and life history. The goal of this research is to provide biological information for sound management of the resource and to develop management alternatives and fishing methods that could be applied to increasing the present harvest.

Introduction

This report is divided into six parts dealing, respectively, with squid productivity in the California Current system; the population biology of *Loligo opalescens;* the animal's reproductive biology; chemical and physical oceanography as related to squid spawning; an analysis of the major squid predators and of the impact of squid as predators upon other marine resources.

(1) Squid productivity

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

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

A three-week exploratory cruise aboard the California Department of Fish and Game's R/V *Alaska* from the Southern California Bight to Monterey Bay was devoted to this effort. Emphasis was directed toward collecting additional specimens for population and reproductive biology studies, gathering and verifying acoustic records, carrying out tag retention studies, and studying distribution of squid larvae on and near spawning grounds. As in previous years, squid were collected by midwater trawling and jig fishing under lights.

Continued work with a bottom fishing plankton net sled in southern Monterey Bay was successful in capturing very young animals (2.0-3.0 mm dorsal mantle length [Fig. 1]) both on and off the traditional spawning grounds; however, large catches, one in excess of 1000 animals, were confined to the spawning grounds. This sampling method holds some promise of indicating recruitment or spawning success, particularly when near spawning areas. Although requiring much refinement in technique, bottom plankton tows could be carried out by small fishery research vessels at low cost.

Tagging of adult *Loligo opalescens* with monofilament nylon showed promise of future utility in tag-recapture studies. Experiments were conducted in *Alaska's* 10,000 gal midship recirculating tank with a tagged (100 animals) group and nontagged (50) control group. Preliminary results indicate a low tagging mortality rate.

During the June *Alaska* cruise and subsequently aboard Moss Landing Marine Laboratories' R/V *Oconostota*, echolocation of squid schools was studied (Fig. 2, 3). Verification of squid echogram traces in shallow water was successfully accomplished by SCUBA diving (Fig. 2). Considerable time aboard *Alaska* was devoted to developing an acoustic survey technique in shallow water; however, the absence of large, verifiable schools (as were detected acoustically in the prior year's *Alaska* cruise) in the survey areas precluded establishing reliability of the technique.

In cooperation with the United States Naval Postgraduate School, Monterey, California,

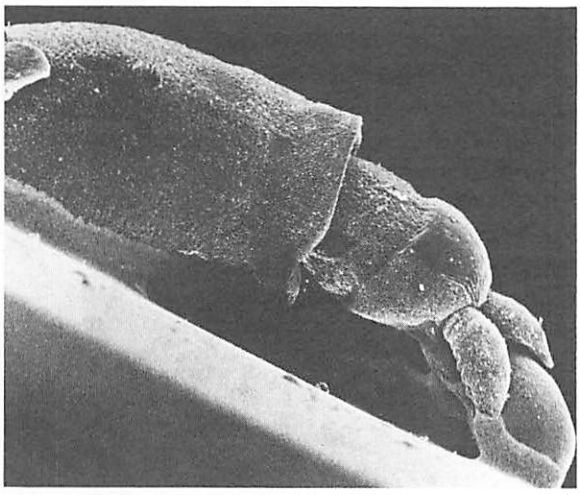


Fig. 1. Scanning electron micrograph of newly hatched squid with protruding yolk sack. 80 x micrograph by James Knipe

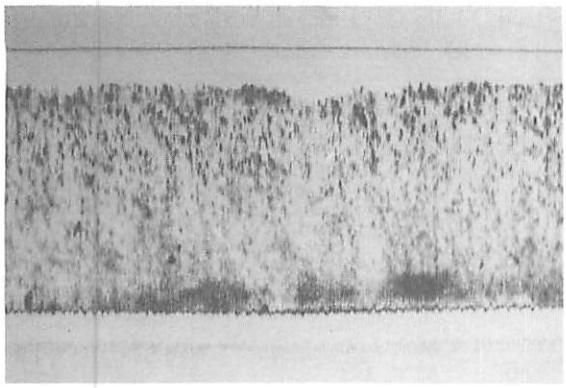


Fig. 2. Echogram (200 kHz) portraying market squid attracted to lights aboard anchored vessel (27 m depth) near Santa Rosa Island, California

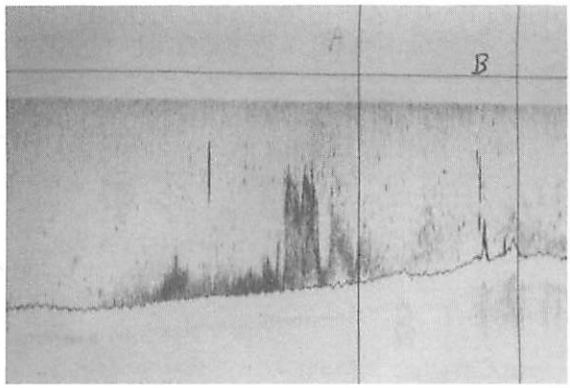


Fig. 3. Night echogram (200 kHz) portraying large shoal of market squid near Santa Rosa Island, California. Vessel is steaming slowly inshore. Shoal is approximately 500 m in horizontal extent

acoustic target strength measurements were carried out on market squid. These measurements were accomplished by comparison of back-scattering cross-section with a reference (39 mm lead sphere). Our measurements were at 200 kHz using an anechoic tank at the Naval Postgraduate School. Eleven fresh-frozen squid were insonified in dorsal aspect. Ventral, anterior, posterior, and left lateral aspects were also studied. In dorsal aspect, i.e., that which would be most often presented to a surveying vessel, squid ranging from 45 to 160 mm dorsal mantle length elicited target strengths ranging from −49.3 dB to −38.8 dB. Our results are comparable to those of Matsui, Teramoto, and Kaneko (1972), who reported a maximum target strength of −42 dB at 200 kHz for a 120 mm squid (*Doryteuthis bleekerei*).

Determination of target strength is an important preliminary step in developing an acoustic abundance estimation technique. Knowing transmitting and receiving characteristics of the echosounding system and understanding target strength of a given size class of target organisms will enable the investigator to specify acoustic sampling volume and range of detection.

(2) Population structure

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

We are engaged in stock discrimination studies of the market squid, using a biochemical-genetic approach (starch-gel electrophoretic separation of proteins coupled with histochemical staining procedures). Using mantle muscle tissue, we conducted an intensive investigation of the enzyme phosphoglucomutase (PGM), a phosphotransferase that catalyzes the reaction converting glucose-1-phosphate to glucose-6-phosphate.

Our standard sample (that with which all other samples were compared) was composed of 1931 squid, and the number of individuals in the 18 smaller samples ranged from 101 to 237. Most samples were of spawning or about-to-spawn animals captured under night-light with jigs and brails over known spawning grounds in California waters.

In our standard sample, males outnumbered females by about 3 to 1. In all but one of the smaller samples, males outnumbered females in a range of from 1.1 to 1 to 49 to 1. Only in one did females outnumber males (1.6 to 1).

Our investigation showed that PGM, in the study tissue, consisted of five allozymes. Of the 15 possible phenotypes which could be produced by the five PGM alleles, 10 were observed (see Table).

In our standard sample, the most common allele was "C," which occurred about 63 per cent of the time; "B" occurred 37 per cent of the time; and "A" and "D" collectively occurred less than 1 per cent of the time. We observed twice the expression of the "E" allele in the phenotypes "BE" and "CE," the former in a Monterey and the latter in a Gaviota sample. Since it was not expressed in our standard sample and occurred only twice in the other samples, nothing conclusive can be said of its occurrence.

To determine the genetic validity of our data, we compared the phenotype distribution

EXEMPLARY PHENOTYPE FREQUENCY DISTRIBUTION OF PHOSPHOGLUCOMUTASE FROM MANTLE MUSCLE TISSUE OF MALE AND FEMALE MARKET SQUID

Sample Date and Locale	Sex	AA	AB	AC	AD	AE	BB	BC	BD	BE	CC	CD	CE	DD	DE	EE	Total
Santa Catalina December 1975	Male		7	8	1		196	653			564	2					1431*
Santa Catalina April 1976	Male		2	1			28	80			82	1					194
Santa Catalina November 1976	Male						36	75			69						180
Gaviota June 1977	Male		1				22	97			77		1				198
Monterey June 1976	Female						18	64		1	39						122

*Reference sample.

of each sample by sex against the Hardy-Weinberg (H-W) equilibrium expectations, using the chi-square test at the 0.05 level of significance. In our standard sample, the male phenotype distribution was consistent with the H-W expectations. However, this was not the case with the females, and we are uncertain why their phenotype distribution deviated from the expected values. The first La Jolla sample and a Santa Cruz Island sample were the only samples whose male phenotype distribution was significant. All smaller samples that had a sufficient number of females to test phenotype distribution were consistent with H-W expectations.

We tested for homogeneity in allele frequency in several ways, using the chi-square test at the 0.05 level of significance. Since the females of the standard sample did not follow the H-W equilibrium expectations, and since several of the smaller samples contained only a few females, we used males in the evaluations.

In certain locations, e.g. off La Jolla, the homogeneity of PGM over time is questionable. The test results suggest that in certain areas genes of two homogeneous groups mix. Results to date indicate that in certain areas allele frequencies of PGM are temporally heterogeneous; i.e., one spawning location may harbor groups of spawning squids having different allele frequencies in time. However, more data gathered over several years are required to substantiate this concept.

The PGM investigation in itself is inconclusive regarding the question of stock discrimination. However, when the results of this work are evaluated with those of the other stock discrimination studies, we may have a firm understanding of the population structure of the market squid.

In an attempt to find additional polymorphic enzymes, digestive gland, mantle muscle and tentacles were extracted and electrophoresed. We tested for a total of 27 enzymes. Of these, 22 gave positive results in one or more of the above tissues. Glutamate oxaloacetate transaminase (GOT) was the only enzyme found to be polymorphic. This enzyme appears to be dimeric in the squid mantle muscle (vertebrate GOT is also dimeric).

To be consistent with the PGM studies, a large base sample was collected from Santa Catalina Island (1600 specimens). This sample has been electrophoresed and scored. Additional small samples (100-300 specimens each) from La Jolla, Pt. Mugu, Gaviota, Monterey (two samples) and Crescent City have been similarly analyzed. Statistical analyses are still in progress. During the coming year more samples will be processed for GOT patterns.

Measurements of squid beaks, which were extracted the previous year, have been completed and analyzed, as have regressions of various beak measurements on dorsal mantle

length. The latter were calculated in order to assess variation in beak morphology with region and sex. These studies were also conducted in order to provide a basic tool to the Food Chain Group for back-calculating prey size from stomach remains. In general, slopes of regression lines of a given beak measurement on dorsal mantle length differ more between sexes than between regions (southern versus central California). For the best "fitting" regression, that of upper hood length on dorsal mantle length, differences between slopes for regions were not significant whereas differences between slopes for sexes were significant. The implication is that beak morphology of *Loligo opalescens* probably cannot be used to separate southern and central California animals.

The beak measurements of upper rostral width and lower hood length appear most practical for predator studies in that these characters are most resistant to digestion. Other beak measurements exhibited less residual error about regression, but they are more prone to destruction by digestive processes. From 215 animals of both sexes and from central and southern California we have determined the following regressions of upper rostral width (URW) and lower hood length (LHL) on dorsal mantle length (DML):

$$LHL = 0.0176\ DML + 0.218$$

$$URW = 0.0102\ DML + 0.216$$

All measurements are in millimeters (Fig. 4).

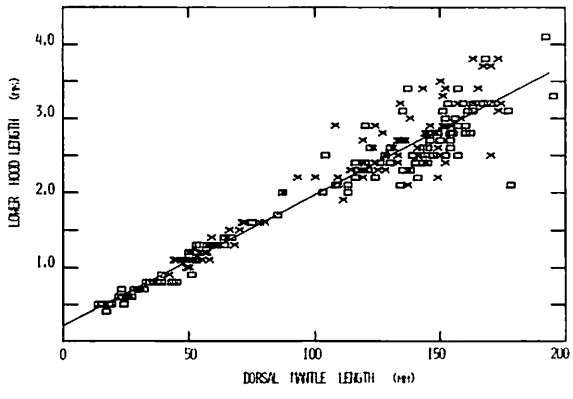


Fig. 4. Regression of beak measurement lower hood length on dorsal mantle length for *Loligo opalescens* of both sexes and for central (square) and southern (cross) California

Samples from the range of market squid are being assembled. In addition to samples collected last year from Mexican waters, this year we have acquired samples from northern California (Crescent City) and Puget Sound.* Morphological variation in these animals is being studied.

(3) Reproduction and age determination

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

Work on male squid reproductive biology and age determination was completed during the past year; work on female reproductive biology is still in progress.

Continuing studies in oogenesis, utilizing histological and histochemical techniques, have led to a further understanding of the nature and composition of the previously analyzed 10 stages of oocyte maturation. The stages of oogenesis which occur previous to oocyte maturation, including germ cell to oogonia and oogonia to oocyte, are being studied in animals from 3 mm (hatchlings) through mature squid. Concurring follicle cells of this stage of oogenesis have thus far proven nondifferentiable. Study of the preceding phenomenon is being carried out, using light and electron microscopy. Recently autoradiography has been employed as a tool to determine the length of time required for the various stages of oogenesis.

To date, reproductive studies in males and females indicate a single spawning event, or season, in life. Evidence that this occurs in males is strong, whereas the adequacy of this model in females has yet to be demonstrated conclusively. Studies of female reproductive biology presently in progress should enhance our understanding of the process.

(4) Oceanography of Monterey Bay squid spawning grounds

Project Leader: W. Broenkow

During the past year, our study of the circulation and mixing of waters near the Monterey Bay squid spawning grounds was completed. Four time series studies were made: three week-long hydrographic investigations using a conductivity temperature-depth profiler (CTD) and flow-through instrumentation were made to describe horizontal

*Courtesy Washington Department of Fisheries, Olympia, Washington.

Fig. 5. Night middepth (10 m) spawning shoal of *Loligo opalescens* in shallow water (25 m) near Monterey, California. Photo by Douglas L. Vaughan

and vertical gradients near the squid grounds; and one 25-hour CTD time series across Monterey Submarine Canyon was made to investigate the possible influence of the internal tide on hydrographic conditions in the squid grounds.

These data have not yet been fully analyzed, but preliminary results show that the inferred circulation patterns indicate a net northerly flow into Monterey Bay around Point Pinos. An upwelling locus in Carmel Bay or further south supplies cool, nutrient-rich waters to this inflow into Monterey Bay. Near Point Pinos, a chlorophyll maximum was observed. This plume-like feature penetrates into the Bay just west (or seaward) of the squid grounds. The time-series study in Monterey Submarine Canyon shows internal tides with amplitudes of 50 to 100 m.

Our results indicate that the tidal mechanism may contribute to the flushing of south Bay waters and, additionally, may disperse deep scattering layer organisms (principally Euphausiids, important squid prey) into shallow waters above the canyon sill depth.

(5) Food chains: Predators

Project Leader: G.V. Morejohn

During our third year of studying the vertebrate predators of squid we were able to demonstrate several important aspects of predation on *Loligo opalescens*. From spawning size of less than 2 mm to breeding adult of 120 to 145 mm dorsal mantle length, squid are fed upon by fish, birds, and mammals. We have attempted to define the extent of mortality of squid (predation) at different squid sizes. Some 20 species of fish fed on squid that ranged in dorsal mantle length from 2 mm to over 155 mm. Squid are fed upon up and down the water column by benthic and pelagic species. At the spawning grounds off Cannery Row, Monterey, the heaviest predation pressure is by the curlfin turbot. Mortality of the one-to-two week old 2 mm long larval squid is as high as 600 young squid per curlfin turbot. Other than this high predation by turbots, fishes ate largely squids in the 35 mm and 100 mm dorsal mantle length sizes.

The heaviest mortality of squid by bird predation is in the 60 mm dorsal mantle length size. The rhinocerus auklet fed extensively on squid between 40 and 90 mm. Sooty and short-tailed shearwaters fed extensively on the 60 and 90 mm sizes. The Pacific fulmar experienced a mass die-off during January-April 1976. A large sample of their stomachs provided us with much information on their feeding habits. This sea bird is obviously a strict feeder of cephalopods. All stomachs contained cephalopods consisting of seven species. Four of the most commonly occurring species were compared as to relative abundance during the collection period; *Loligo opalescens* was one of these species. Comparison of water temperatures in the bay with collection times revealed that *Loligo opalescens* was sensitive to a 2°C change in surface temperature, and availability to predation by fulmars (within 2 meters of the surface) decreased or increased with temperature changes. During the fall-winter of 1975 and the spring of 1976, California sea lions along Cannery Row, Monterey, fed almost exclusively on squid ranging from 100 to 145 mm in size.

Our studies on the comparative energy flow of squid versus anchovy through sea birds (sooty shearwaters) have not terminated. Ames Research Center at Sunnyvale has agreed to assist in our program. We have made detailed calorimetric analyses of 22 squid and found that mature females have higher calorimetric content than adult males; and adult squid of either sex have proportionally higher energy content than juveniles. Twenty-five birds were kept in captivity for one week each and fed known amounts of market squid or northern anchovies. All excreta were collected for energetic analysis. We are still in the final stages of this study, but our results should yield good information on the relative assimilation efficiencies of squid versus anchovy and the relative digestion rates of each.

(6) Food chains: squid prey and competitors

Project Leader: G.M. Cailliet

Squid from Monterey Bay fed mostly on crustacea, but also on fish, cephalopods, gastropods, and polychaetes. Animals from deeper offshore waters fed more on euphausiids and copepods. Inshore, off the spawning grounds, euphausiids were also important, along with mysids, megalops larvae, cephalopods, and fish. On the spawning grounds, feeding habits changed a great deal. Here, crustacean feeding still dominated, although euphausiids were lacking from the diet. Demersal feeding became most important, with such items as megalops larvae, egg-like spheres, juvenile gastropods, and nereid polychaetes comprising the diet. Little difference in prey composition was found between sexes on the spawning grounds, or between large and small squid from non-spawning ground areas.

Laboratory and field digestion experiments demonstrated that *Loligo opalescens* has a high rate of digestion. Stomach emptying times ranged from 6 to 14 hours in the laboratory to 6.6 hours in the field. The type of food, whether fish or crustacea, did not appreciably affect stomach emptying times in the laboratory. Larger meals tended to take longer to clear.

Qualitative indices ranking the phases of digestion and fullness were developed and tested in laboratory feeding experiments and in the field. These were used to study diel feeding periodicity. Peak feeding occurred during daylight hours, with the largest average meal size of 6.3 per cent dry body weight occurring at midday. Feeding intensity was greatest between 0900 and 1200 hours, with a small increase between 1500 and 1600 hours.

The catches of large midwater trawls and commercial anchovy purse seine hauls were analyzed for recurrent assemblages of pelagic organisms in Monterey Bay. In all, 71 samples, taken in the upper 50 fathoms using large midwater trawls aboard the R/V *Alaska*, were examined. From similar depths and locations, 29 commercial anchovy hauls were subsampled as they were being unloaded in Moss Landing Harbor. Analysis of ranks of relative abundance for the dominant taxa and recurrent groups indicated that both methods showed similar pelagic assemblages despite the obvious differences in purpose of sampling and type of gear. In general, catches were dominated by market squid and northern anchovy, but other frequently occurring organisms were juvenile rockfishes, Pacific hake, scyphomedusae (*Pelagia* and *Chrysaora*), Pacific electric ray, Pacific sanddab, plainfin midshipman, white croaker, Pacific butterfish, Pacific herring, and euphausiids.

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

Lasley, S.R., 1977, Hydrographic changes in Monterey Bay surface waters in relation to nearshore circulation. M.S. thesis, Moss Landing Marine Laboratories, Moss Landing, California.

Cooperating Organizations

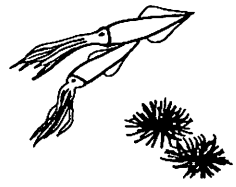
California Department of Fish and Game, Eureka, Long Beach, and Monterey, California

California Marine Research Committee

National Aeronautics and Space Administration, Sunnyvale, California

National Marine Fisheries Service, Seattle, Washington; Tiburon, California

Washington Department of Fisheries, Olympia, Washington



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

Paul K. Dayton and Joseph H. Connell

The California sea urchin fishery has grown from 200 lb to more than 9 million lb per year since its inception in 1971. The rapid growth of this fishery has been based on the take of virgin stocks. At San Diego, the final year of this three-year research program has been devoted to completing the studies of urchin natural history and population dynamics necessary to manage a sustained-yield fishery. At Santa Barbara, the hypothesis was examined that the red sea urchin fishery would reduce grazing pressure, and thereby lead to increases in giant kelp populations by experimental studies of two questions: 1) Do red and purple sea urchins compete and will removal of reds result in larger purple urchin populations? and 2) What are the relative grazing effects of similar biomasses of the two urchin species?

SEA URCHIN NATURAL HISTORY AND POPULATION DYNAMICS

A major accomplishment to date has been the elucidation of the settling biology of the commercially exploited red urchin, *Strongylocentrotus franciscanus.* Small red urchins spend their first year hidden under the spine canopies of adult red urchins, where they share the larger animal's food. These young are exposed to predators when the adults are harvested; we have demonstrated decreased settlement and/or survival of young urchins in fishing experiments (Tegner and Dayton, 1977). Knowledge of this spine canopy association is of fundamental importance to the management of the red urchin fishery, because it means that harvesting removes nursery grounds as well as reproductive potential. On the basis of our data, the State of Washington has instituted upper and lower size limits to ensure adequate recruitment into fished areas. The need for such regulation has been demonstrated in British Columbia. Canadian scientists (Breen *et al.*, 1976) have reported that where all red urchins were removed by the fishery, there were no young urchins four years later. Clearly, some provision for this nursery function must be made to ensure sustained-yield fishing.

The size of animals which can perform the nursery function is thus of special importance for continued recruitment in this size-selective fishery. We studied the nursery association in an area of Santa Barbara Island which had been harvested. With most of the adult red urchins larger than 100 mm gone, the juveniles had to go elsewhere. Large numbers of small urchins were found under adults in the 80-90 mm size range, but some were under urchins as small as 40-50 mm. While a recruit will grow too big for the spine canopy of a 40 mm urchin fairly rapidly, it does provide some protection for the crucial first months of the recruit's benthic life. Thus the presence of intermediate size classes appears to be very important for the successful regrowth of an area after fishing. We also repeated an experiment at our Point Loma study area to look more closely at the variation of recruitment rates over a wide range of adult densities. No correlation of recruitment with number of adults or adult density was found beyond the threshold of one adult's presence. This is probably due to the fact that large numbers of small recruits can find shelter under one adult urchin. We have observed up to 38 young in one nursery association.

Participation in research cruises

This year we participated in two cruises to the Channel Islands with the Department of Fish and Game on their research vessel, the RV *Kelp Bass.* The object of these cruises was to examine urchin populations where most of the harvesting is being done and to attempt to assess the impact of the fishery. Size-frequency distributions showed two basic population structures. In some areas, there were urchins in a wide spread of size categories. In others, the populations consisted mostly of large adults. In areas which had been fished we saw some populations with large numbers of smaller animals, suggesting that recovery to fishable concentrations would be relatively

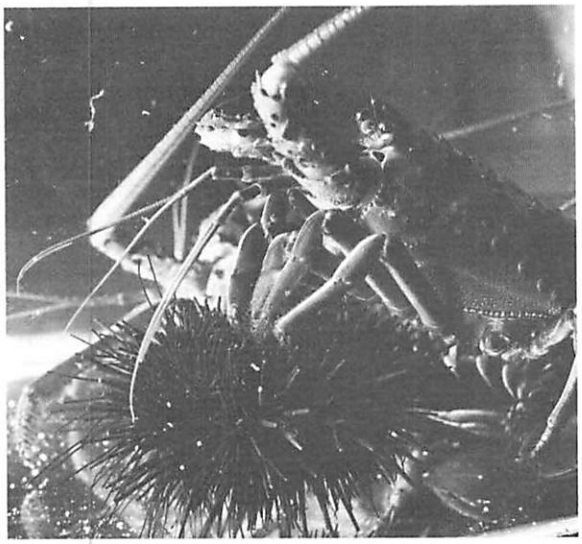


Photo by Larry Ford, SIO

The spiny lobster, *Panulirus interruptus,* uses its anterior walking legs and third maxilipeds to break into the oral surface of the red urchin, *Strongylocentrotus franciscanus.* Spiny lobsters are capable of taking adult red urchins, even while the urchins are attached to the substrate by going through the aboral surface

rapid. In other areas, fishing had removed virtually all the urchins. In the absence of immigration, recovery of such areas could take years unless some provision is made to leave a few adults behind.

Sea urchin reproduction studies

A major part of our effort this past year has been devoted to studies of urchin reproduction. We have been using the gonad index, the ratio of gonad weight to the total wet weight of the urchin, as a measure of reproductive effort. In addition to cyclic changes in gonad size related to reproductive state, the gonad index is clearly dependent on food supply, as shown by feeding experiments conducted in both the field and laboratory. In other words, if food is limiting, the animal uses what energy it has for basic metabolic needs, and gamete production suffers. As a result, the gonad index can be used as an indication of the relative health of urchin populations under different conditions.

These results were applied recently during a controversy between urchin fishermen and Kelco, a San Diego based kelp-harvesting concern. Fishermen were protesting Kelco's continued use of quicklime to control urchins in plague situations. Working with Kelco and Fish and Game biologists, we analyzed size-frequency distributions and gonad indices to demonstrate that urchin harvesting would not have saved the kelp in test situations. Our data on the dependence of gonad index on food supply further prove that these animals will be of no value to the fishery until their kelp food supply is restored. We will be helping to monitor further tests of urchin fishermen's ability to replace control by quickliming in plague situations.

Predator studies

To gain a better understanding of sea urchin distribution and abundance patterns, we intensified our studies of urchin predators this year. South of the range of the sea otter, the main predator of adult red urchins appeared to be the California sheephead, *Pimelometopon pulchrum.* To document predation patterns, we regularly sampled censused populations for the tests of dead animals. Starfish, which prey on purple and young red urchins, and sheephead leave tests in a characteristic manner after they have consumed the soft parts of their prey. Tests characteristic of starfish and sheephead predation constituted most of our samples, but a varying portion remained unexplained.

Spiny lobsters *(Panulirus interruptus)* and cancer crabs *(Cancer antennarius* and *C. productus)* are occasionally present in our study areas. As both lobsters and crabs are nocturnal, we have had little chance to observe their feeding behavior in the field. To find out whether these predators would and could take sea urchins, we presented the crustaceans with urchins in the laboratory. We found that both lobsters and cancer crabs can break into the heavy test of an adult red urchin and consume it. The irregular holes made in the tests of urchins consumed by these predators appear to account for the mortalities not due to sheephead and starfish.

Lobsters are the object of an intensive commercial fishery in the Point Loma kelp bed and sheephead are prized by both spear and pole fishermen. Not surprisingly, populations of both predators have declined in recent years. We have observed considerably higher densities of both sheephead and lobsters in offshore locations such as San Clemente Islands and Cortez Bank, and preliminary data suggest that these increased predator densities

have major effects on urchin population dynamics.

EFFECTS OF FISHING ON THE KELP COMMUNITY — Research at Santa Barabara

The red sea urchin *(Strongylocentrotus franciscanus)* fishery in southern California was initiated to develop an economically valuable marine resource (i.e., sea urchin gonads), and to control sea urchin populations, which were assumed to exert negative effects on giant kelp and abalone populations. Although the effects of sea urchins on giant kelp populations have been studied extensively, the work has for the most part been non-experimental, and the causal relationships between fluctuations in giant kelp and sea urchin populations are poorly understood. The same holds with greater force about presumed relationships between sea urchin and abalones.

Our aim was to experimentally test the assumption that the red sea urchin fishery would reduce grazing pressure on giant kelp. The fishery takes only red urchins. It leaves purple urchins *(S. purpuratus)*, congeners which are also abundant in the subtidal. Purples and reds occupy similar habitats, have similar diets and both species have been observed to over-graze local kelp populations. Because of the ecological similarity of the two species, we hypothesized that they compete, and that removing reds would lead to increases in purple sea urchin populations. If this were true, the ultimate effects of the fishery on kelp populations would depend on the sizes of the increases, and on the relative grazing effects of the two species.

Field removal experiments

The distributions of reds and purples differ in intertidal boulder field and tidepool habitats on Santa Cruz Island. In both habitats purples occur higher in the intertidal than reds, and reds dominate the low intertidal. In boulder fields, the different distributions were also shown by the fact that purples dominated the tops of the boulders (291 vs. 46 at the bases) and reds dominated the bases (116 vs. 30 at the tops). Since the tops of the boulders were higher in the intertidal, they were physically harsher than the bases, and also received more water motion (Schroeter, 1978). These observations, combined with the fact that purples responded better to benign than harsh conditions in field and laboratory experiments (Schroeter,1978), suggested that purples were less abundant around the bases because of competitive interactions with reds rather than responses to physical factors.

The following experiment was done three times to test this hypothesis: Reds were removed from the bases of intertidal boulders to determine their possible effects on purples. Controls consisted of boulders from which reds were removed and then replaced. Under competition we expect one or both of the following changes in purple urchin distributions on boulders: 1) movement from the tops to the bases, and 2) immigration to the bases from surrounding areas. Individual urchins were not marked, so that movements were inferred from changes in their abundances on the tops and around the bases (i.e., decreases on the tops and increases around the bases were interpreted as movement from the tops to the bases).

To summarize the results of the three removal experiments: When reds were removed from the bases of intertidal boulders, purples quickly moved down from the tops (Table 1). Temporal changes in the abundances of reds and purples were negatively correlated around the bases of all boulders (Fig. 1). These results support the hypothesis that reds and purples compete, and that removing reds results in increased abundances of purples.

In the above experiments, change of purple urchin populations was due primarily to immigration following the removal of reds. These increases were temporary; reds reinvaded the experimental areas and forced purples back out. We conducted another series of removal experiments in isolated low intertidal pools dominated by red urchins, hoping to prevent reinvasion of reds, thereby observing any long term effects of removing reds on purple sea urchin populations. The experiment consisted of removing all adult red urchins from one of two low intertidal pools (each about 8 m^2 in area) that had similar abundances of both species (reds dominated and purples were rare). The reds were removed and replaced in the other pool as a control. Changes in the abundances of both species were monitored in permanent, uniformly placed quadrats for about a year and a half.

Immigration and recruitment of purple urchins were higher in the removal than in

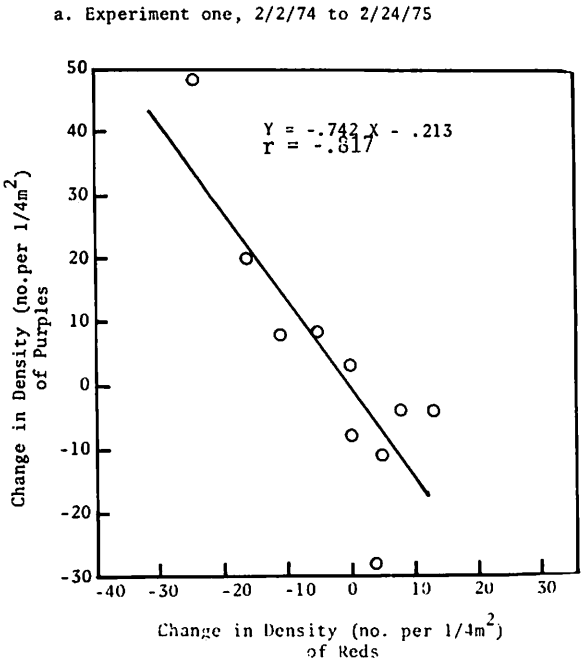


Fig. 1. Correlations between changes in the abundance of reds (x) and purples (y) at the bases of boulders during one of three red urchin removal experiments. The regression equations and r values for the other two experiments were as follows:

b. $Y = -1.392 x + 0.051$ $r = -0.539$

c. $Y = -0.645 x + 0.372$ $r = -0.521$

the control pool. There was little net immigration or recruitment of red urchins in either pool during the experiment (Table 2), so that purples eventually dominated the experimental pool, again supporting the hypothesis that removing reds leads to increases in purple urchin populations.

Field growth experiments

The above experiments detected competition by measuring changes in purple urchin population sizes following the experimental removal of reds. We also wanted to see whether reds would affect the growth rates (and thereby the productivity) of purple urchin populations in habitats where the two species occur. We did this by comparing body and gonad growth of purple urchins with and without red urchins, in cages placed in subtidal habitats.

The cages were designed to prevent urchins from moving in or out, but allowed their food, drift algae, to enter. Experiments were run at two densities (normal: comparable to nearby field densities, 48 individuals per m^2; and 2x normal: 96 individuals per m^2) with three treatments (each confined to an individual cage) per density (reds only, purples only, and equal numbers of reds and purples). Similar-sized individuals of both species were used in the different treatment combinations.

Two separate, similarly designed experiments were performed; each lasted about one year. Body growth was estimated by measuring changes in test diameters during each

TABLE 1

Effects of reds on purples. Change in the abundances of red and purple urchins on the tops and at the bases of intertidal boulders during one of three different experiments. The results of the other experiments were similar. Reds were removed from the bases of experimentals and were removed and replaced at the bases of controls.

	Experimentals (red urchin removals)				Controls			
Sampling Date	n	Purples on tops of boulders	Purples around bases of boulders	Reds around bases of boulders	n	Purples on tops of boulders	Purples around bases of boulders	Reds around bases of boulders
July 18, 1974*	5	10.9 (2.4)	3.7 (2.6)	3.6 (0.7)	3	11.2 (0.6)	1.7 (0.6)	2.3 (0.7)
July 21, 1974	3	5.4 (2.3)	—	—	2	10.6 (2.2)	—	—
December 10, 1974*	5	3.5 (1.3)	2.8 (1.1)	2.7 (0.9)	3	8.3 (1.1)	1.4 (1.1)	3.1 (0.3)
December 11, 1974	5	2.4 (1.0)	4.9 (1.8)	0.1 (0.0)	5	8.4 (1.1)	1.4 (1.1)	3.0 (0.4)

*Dates on which red urchins were removed.

TABLE 2

Effects of reds on purples in two low intertidal pools. Adult reds were removed from one (Removal) on March 25, 1975, and were removed and replaced in the other (Control) on the same date.

Dates	REMOVALS				CONTROLS			
	Reds		Purples		Reds		Purples	
	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles
March 25, 1975*	0.6 (0.1)	0.0 (0.0)	2.0 (0.4)	0.7 (0.2)	1.2 (0.2)	0.0 (0.0)	1.4 (0.4)	0.1 (0.1)
October 25, 1976	0.0 (0.0)	0.0 (0.0)	6.2 (0.9)	5.3 (1.1)	2.1 (0.3)	0.2 (0.1)	2.8 (0.5)	2.0 (0.5)

*Date on which adult reds were removed.

experimental period. Since individuals of the same species were collected at the same time from the same habitats, and were the same size at the beginning of each experiment, we assumed that their gonads were also the same size. Using this assumption, we estimated differences in gonad growth among the treatments by comparing gonad indices (wet gonad weight/wet total weight X 100) among the different treatments at the end of each experiment.

Any statements of differences among treatments are based on a multivariate analysis of variance procedure, the details of which are presented in Schroeter (1978). For ease of present interpretation, the average test diameters, and gonad indices of both species in the different treatments are presented in Table 3.

In the first experiment, purples grew faster in single compared to mixed species treatments at both densities. There were no differences in the growth of reds in mixed and single species treatments at normal density; but at twice normal density, reds grew significantly better when with purples than in single species treatments (Table 3). Gonad indices were higher for purples in single compared to mixed species treatments at both densities. There were no differences between the gonad indices of reds in single compared to mixed species treatments at either density, although the gonads of reds were larger at twice normal than at normal density (Table 3).

The results of the second experiment were similar to the first with two differences: 1) Body growth of purples was not significantly greater in the single versus mixed species treatment at normal density, and 2) there were no differences in gonad indices of reds in normal compared to twice normal densities (Schroeter, 1978).

Studies of relative grazing effects

We conducted two pilot experiments to see how the same biomasses of reds and purples would affect giant kelp and the brown alga, *Egregia*.

In the first experiment, similar biomasses (2.5 kg of either red or purple urchins were placed on separate holdfasts (purples were placed on two and reds were placed on two) of similar sized kelp plants growing on the seawater intake pipes at UC-Santa Barbara (a group of urchins consisted either of eight reds with test diameters of 8 cm, or 32 purples with test diameters of 5 cm). A difference in the way the two species affected the holdfasts was apparent on a census two weeks after they were placed in the field. All of the reds moved off the holdfasts, but 32 and 10 purples remained, and all had begun to burrow (in some cases, individuals burrowed completely below the surface of the holdfast). These individuals were present on two subsequent monthly censuses, and continued to burrow into the holdfasts. The experiment was not continued long enough to determine whether the burrowing increased the probability of kelp mortality, but the results suggest that purples could have more severe negative effects on kelp than reds.

The other experiment consisted of noting differences in algal development on three 1/4 m^2 concrete slabs placed inside separate cages in the low intertidal (-0.6m) near the UC-Santa Barbara campus. The three cages

TABLE 3

Effects of the presence of another species and of population density on body size (average test diameter and length of subamital plate*) and gonad size (gonad index) in two field growth experiments, October 27, 1974 – September 20, 1975.**

Species Combination	Density	Body Size					Gonad Size	
		n	Average test diameter (mm) at beginning (± S.E.)	n	Average test diameter at end (± S.E.)	% Increase in average test diameter	n	Average gonad index at end of experiment
Purples only	Normal	12	34.9 (1.2)	10	46.4 (0.8)	32.9	10	10.7 (0.9)
Purples with reds	Normal	6	35.8 (0.9)	6	44.6 (1.2)	24.6	6	7.2 (0.7)
Purples only	2 X Normal	24	35.2 (0.5)	17	46.5 (2.8)	32.1	17	10.4 (1.0)
Purples with reds	2 X Normal	12	34.3 (1.2)	6	42.4 (2.8)	23.6	6	7.6 (1.0)
Reds only	Normal	12	37.0 (0.7)	10	52.0 (1.3)	40.5	10	6.1 (1.3)
Reds with purples	Normal	6	37.3 (1.0)	6	52.0 (1.1)	39.4	6	5.8 (0.8)
Reds only	Normal	24	35.8 (0.7)	18	50.0 (0.8)	39.7	18	8.9 (0.5)
Reds with purples	Normal	12	36.9 (0.8)	8	54.0 (1.1)	46.3	8	9.1 (0.9)

*A calcareous plate in an urchin's test that lies just below the largest meridianal circumference.

**Gonad Index = $\frac{\text{Wet Weight of Gonad}}{\text{Total Wet Weight}} \times 100$.

contained reds, purples, and equal numbers of reds and purples, respectively. Equal numbers (14) of similarly sized urchins (3 cm in test diameter) were in each cage. The most striking difference between the slabs was in the abundance and condition of the brown alga *Egregia* sp. Four months after the urchins were placed inside the cages, the concrete slab with the reds contained 33 *Egregia sporophytes*, none of which had obvious grazing marks. The slab with the purples contained no sporophytes; the one with equal numbers of reds and purples contained three sporophytes with extensive grazing marks.

Conclusions

Selective removal of red sea urchins resulted in increases in the size and productivity of purple sea urchin populations, a species that has also been shown to over-graze kelp populations. Further experiments indicated that a given biomass of purples has a greater negative effect on giant kelp and the brown alga, *Egregia*, than the same biomass of red sea urchins.

Publications

P. K. Dayton:

Tegner, M. J., Recruitment patterns of *Strongylocentrotus franciscanus* and *S. Purpuratus:* Implications of the commercial sea urchin fishery. Paper presented at the Western Society of Naturalists' meeting at California State University, Fullerton, December 29, 1976.

Tegner, M. J., and P. K. Dayton, Sea urchin recruitment patterns and implications of commercial fishing, *Science*, 196, 324-326 (1977).

J. H. Connell:

Schroeter, S. C., The influences of physical harshness, competition, and predation on the distributions of red *(Strongylocentrotus franciscanus)* and purple *(Strongylocentrotus purpuratus)* sea urchins in southern California. Ph.D. dissertation, University of California, Santa Barbara, 1978.

Cooperating Organizations

California Department of Fish and Game, Sacramento, California

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

Endocrinology of Salmon Smoltification and Adaptation to Seawater

Berkeley
R/F-25

Howard A. Bern

In order to understand the cause of stunting (failure to grow and adapt) of coho salmon when they are transferred to seawater, an analysis of the endocrine systems of developing salmon at various stages is being undertaken. When the hormonal mechanisms responsible for the transformation of salmon parr to smolt and for adaptation to seawater are delineated, it should be possible to pinpoint the nature of the dysfunction in the stunt that is responsible for the loss of so many hatchery-raised salmon at the critical time of entry into seawater. This knowledge could then lead to measures to avoid these economic losses.

After hatching, the coho salmon, *Oncorhynchus kisutch*, normally spends one or more years as a freshwater parr before becoming a smolt and migrating to the sea. There it grows to adulthood after one to three years and returns to fresh water to spawn. When young coho salmon (usually accelerated in growth) are transferred into sea pens in order to enhance further growth before release or harvest, as many as 50 per cent die within a few days or become stunted and die later. The stunting phenomenon is presumably associated with the inability of the endocrine system and target organs of the young salmon to cope with the drastic environmental change from fresh water to seawater. A comprehensive understanding of the biology of parr-smolt transformation and of the mechanism of seawater adaptation is necessary to provide a rational basis for avoiding this economic loss.

Endocrine gland involvements

It is possible that the stunting of salmon, and the poor adaptation to seawater life which it reflects, may be the result of the failure to turn on needed hormonal functions (possibly the thyroid, the adrenal cortex equivalent, the growth hormone cells of the pituitary) or the failure to turn off unwanted hormonal functions (for example, the prolactin cells of the pituitary). Comparison of various endocrine glands from smolts with those taken from stunts in seawater revealed significant differences. The pituitary cell type controlling the activity of the thyroid and consequently the thyroid gland itself were regressed in the stunt when compared with the smolt. In addition, the pituitary cells controlling the interrenal (adrenocortical) tissue were much less active in the stunt, and this is true also of the interrenal tissue. However, the difference was not so clear with regard to the growth hormone cells. Although the stunts in seawater were roughly half the size of the smolts, their growth hormone cells were only slightly less active.

Other endocrine organs also appeared to show decreased activity in the stunts as compared with the smolts. Further study is needed to determine which endocrine dysfunction(s) may be primary, thus contributing to the maladaptation of the stunt, and which may be secondary, resulting from the abnormal physiology of the stunted fish.

Body composition changes

Metabolic changes are to be expected when a fish enters seawater from a freshwater environment. Analyses of blood, liver and muscle show that the smolt, while still in fresh water, is much altered from the parr in preparation for seawater survival. Serum protein, glucose and lipid levels, in addition to total liver and muscle lipid, are significantly lower in freshwater smolts than in parrs, which suggests increased catabolic activity prior to and in anticipation of seawater migration. Smoltified fish that do not reach seawater by late summer revert to a parr-like appearance and also reattain some of the biochemical characteristics of parrs (high body fat and glycogen). In seawater, the stunts show muscle protein levels significantly higher than in the smolt. This abnormality may reflect a fundamental and irreversible change in metabolic pattern of these maladapted fish.

Detection of smoltification

There are basically two methods to determine the degree of smoltification. Both labo-

ratory procedures are not adaptable to field usage. One technique uses gill homogenates to determine Na^+, K^+–ATPase concentrations; the other requires a seawater challenge followed by plasma sodium determination. Our particular method is based on a simple microscopic examination and tabulation of the number of chloride cells of the subopercular epithelium after preliminary fixation in a dichromate fixative of a small piece of tissue, taken without necessarily killing the fish. This technique is rapid and easy to perform, but requires considerable further assessment as a means of judging smoltification.

Cooperating Organizations

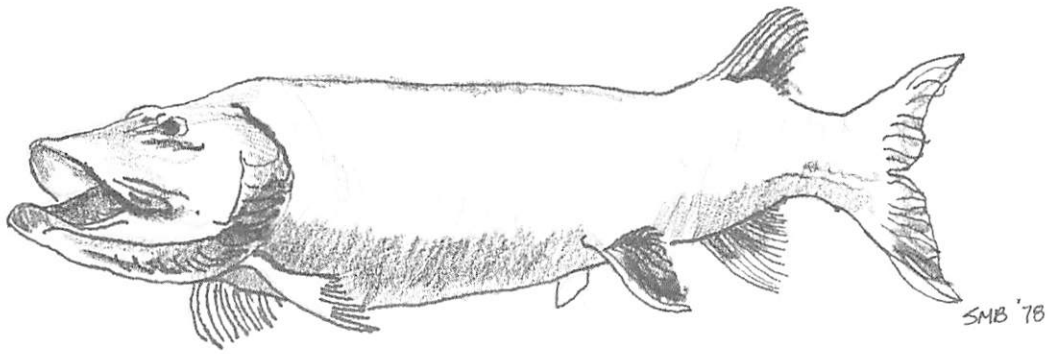
Feather River Hatchery, California Department of Fish and Game, Oroville, California

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

National Marine Fisheries Service, Tiburon, California

Pacific Biological Station, Nanaimo, British Columbia, Canada

University Cooperative Extension, Sonoma County, California



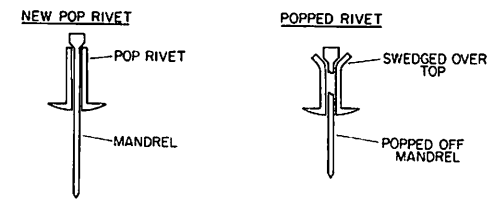
Development of a Mechanism to Allow Release of Dungeness Crabs from Lost or Abandoned Pots

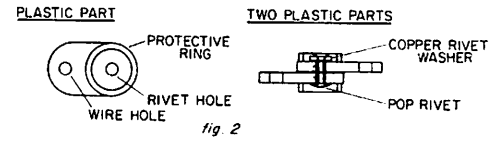
Frank Jolly

Along the Pacific coast north of San Francisco, a thriving trap fishery for Dungeness crabs forms a significant part of the commercial fishing effort. It is inevitable that each year some crab pots are lost and others abandoned. Recovery of abandoned pots, as well as experiments with unbaited pots, have given indications that crab traps left for long periods on the ocean floor will continue to catch crabs. It is desirable, therefore, to incorporate into the structure of the traps a means of allowing crabs to escape from those which may be abandoned.

The major objective of this project was to develop a failure device which will open a lost or abandoned crab trap in a specified time. A steel pop rivet in combination with a copper washer holding two pieces of polypropylene plastic together gave consistent and reliable results. The plastic parts which insulate the device from the stainless steel fabric of the pot separate to create a large opening in the fabric of the trap after the copper washer has destroyed the steel pop rivet (Fig. 1). The surface area and the mass of the copper washer in relation to that of the steel rivet determine the time that a particular combination will last in seawater. The devices are placed in the tops of the crab pots (non-lid half) over the tunnel. Two of the mesh wires are cut, folded back, and tied off, leaving a large diamond-shaped opening across which the failure device is wired (Fig. 3). The topside location for the failure device was chosen because it would be the least likely spot to bury in sand; the lid latch is inappropriate because barnacles soon render it inoperable.

One of the potential problems of a failure device is encrustations of marine life cementing the device in such a way as to prevent separation or opening. The device also had to be able to withstand impacts and rough handling up to the time of expected failure; it had to be inexpensive; and it had to fail within a predictable time period. The combination of copper and steel best fit these requirements; in particular, the copper was an especially useful component because its toxicity to most marine organisms prevented encrustation. Other metallic combinations tested included aluminum with stainless steel, aluminum with steel, and brass with steel.





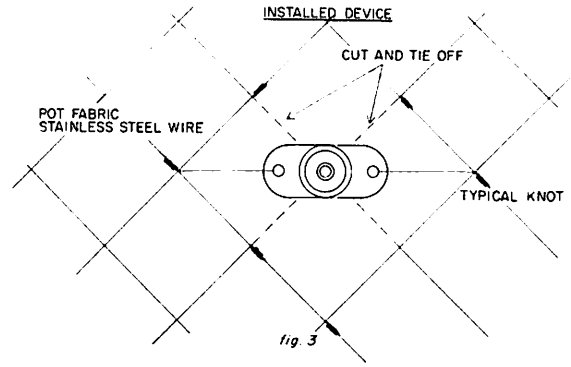


Fig. 1. A steel pop rivet in combination with a copper washer is used to hold two pieces of polypropylene plastic together

Fig. 2. Each of two polypropylene injection-molded parts has a hole in the center of a cup-like depression to hold the pop rivet and a second hole to wire the device to the trap

Fig. 3. The failure device is wired across a large diamond-shaped opening in the crab trap fabric formed when two mesh wires are cut and folded back

Plastics tested for the failure device included ABS, polycarbonate, acrylic, polypropylene, and polyethylene. Barnacles adhered readily

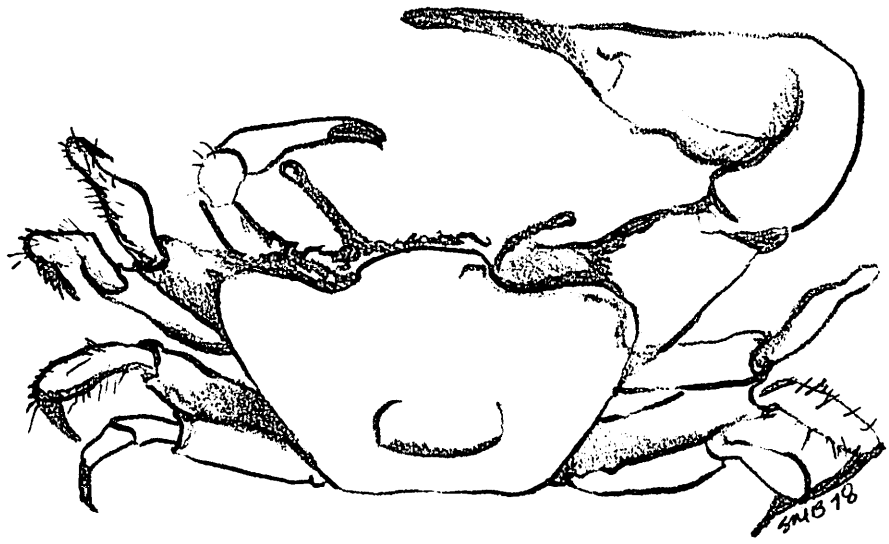
and solidly to ABS, polycarbonate, and acrylic. Polyethylene was somewhat resistant, but polypropylene offered the best combination of resistance to barnacles, and strength. The two plastic parts, made by an injection molding process, each had a hole in the center of a cup-like depression to hold the pop rivet, and a second hole used to wire the device to the pot (Fig. 2).

Test results, although not completed, have given the following time spans for two rivet and copper burr size combinations: 1) A 1/8 in steel rivet with a No. 9 copper rivet burr will fail in 109 ± 3 days; and 2) a 5/32 in steel rivet and a No. 9 copper burr will fail in 210 ± 10 days. When pots equipped with failure devices are placed in shallow water (less than 10 fathoms), failure times were shortened, probably because of increased water turbulence. In water depths of 10 fathoms or greater, the devices showed no appreciable variation in failure from expected times. No difference in catch success between test and control pots was detected.

Thus far, 2000 devices have been constructed and distributed to selected crab fishermen for the 1977-78 season. Rivet and burr combinations to be tested include 1/8 in steel rivets with No. 9 and No. 10 copper burrs, 5/32 in steel rivets with No. 7 and No. 8 copper burrs; and a 3/16 in rivet with a No. 6 burr.

Cooperating Organizations

California Department of Fish and Game, Eureka, California



The Effects of Food Availability on the Growth and Survival of Jack Mackerel Larvae

M. M. Mullin and Reuben Lasker

The management of commercial fisheries to optimize production while preventing overfishing requires an understanding of the relationship between the abundance of fish in successive generations. This relationship depends on the survival and growth rates of young fish. The object 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 average densities of plankton found in the sea.

It has commonly been observed that most first-feeding fish larvae raised in the laboratory require very high concentrations of food to survive, much higher than those 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 those in the laboratory; or whether the only larvae that 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 experience very low growth and high mortality rates due to starvation.

Jack mackerel are one of the most abundant types of fish larvae found by the biannual egg and larva surveys made by the California Cooperative Oceanic Fisheries Investigation (CalCOFI) of the California Current. The species' estimated biomass is 2-5 m. tons, which represents a sizable, underutilized resource for sports and commercial fishing. While much work has been done everywhere 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 inadequate for anchovy or sardine larvae.

Laboratory experiments

The first 12 months of the project have been devoted primarily to laboratory experiments to determine how well mackerel larvae survive and grow when exposed to controlled, low 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 fish larvae. Preliminary results are that some larvae survived at the low, "natural" densities, but in lower numbers than obtained in experiments with high food density. The daily feeding success, types of food eaten, and growth rates of the larvae in each experiment are being determined by microscopic observation of preserved specimens.

In order to assess the actual feeding success of jack mackerel larvae in the sea, morphological measurements and gut content analyses are being done of preserved specimens of wild larvae collected by the CalCOFI sampling program. Also, field work is planned for the 1978 spawning season in which larvae will be collected at sea simultaneously with the collection of plankton samples from the waters inhabited by the larvae. Comparison of the gut contents of the larvae with the types and densities of plankton found in their vicinity will show what type of prey selectivity the larvae actually exhibit in the wild, and how much food they obtain under known conditions of food availability and, perhaps, the degree to which the larvae successfully seek plankton concentrations in their area. The plankton-collection procedure will be designed to maximize the information available on the degrees of spatial aggregation or "patchiness" displayed by various types of small zooplankton in areas where larvae are collected. By applying the results of the laboratory feeding experiments to the measurements of feeding success of larvae caught at sea, it will be possible to estimate the starvation rates or growth rates of the wild larvae. These data, plus those on overall levels of plankton abundance over a large area, permit estimation of the proportion of fish larvae that would have sufficient food for survival in any particular spawning season.

Cooperating Organizations

National Marine Fisheries Service, Southwest Fisheries Center, San Diego, California

Studies of Fish Muscle Proteins and Fresh and Frozen Seafood Technology

W. D. Brown

Fish begin to undergo subtle deleterious changes following their capture, with one of the more undesirable being the development of fishy odors and flavors commonly associated with poor quality. Ordinarily, refrigeration and/or freezing is employed for transportation and/or storage of seafoods. However, a means to make possible longer transport times, longer shelf lives and better quality would be very desirable. This research was intended to investigate the effectiveness of combining modified atmospheres with refrigeration for this purpose.

Controlled-atmosphere storage of fish

It has long been known that elevated levels of carbon dioxide inhibit microbial growth on the surface of fish and meats. For reasons that are somewhat obscure, application of this knowledge has been slow to come. With the support and technical assistance of personnel of TransFresh Corporation, we have investigated in some detail the use of controlled atmospheres for storage and transport of fish products. The preliminary study was with rex sole and red snapper and demonstrated the potential of the use of gas mixtures containing elevated levels of carbon dioxide (50 per cent). During the year of this report period, a more detailed investigation with salmon and red snapper samples has been completed.

In this study, salmon steaks and red snapper fillets were placed on stainless steel racks designed to fit in specially built containers approximately 1 foot in diameter and 3 feet tall, which could be sealed, and which were fitted with gas inlets. Samples were stored in either 20 per cent or 40 per cent carbon dioxide (balance air) and in air (controls). The chambers were kept under refrigeration, and samples were removed periodically for chemical, microbiological, and sensory analyses. It has been demonstrated in darker fish and in red meats that elevated levels of carbon dioxide induce the oxidation of the myoglobin pigments, resulting in a dark surface appearance. In the presence of small amounts of carbon monoxide, a pigment is formed which is visually indistinguishable from that normally seen, but which for reasons unknown does not undergo the undesirable oxidation reaction. For this reason, some samples of fish were also stored in atmospheres containing low levels (1 per cent) of carbon monoxide together with the elevated levels of carbon dioxide.

Chemical assays performed included peroxide values and thiobarbituric acid assays for lipid oxidation; determination of hypoxanthine levels as an indicator of "freshness"; and assay of trimethylamine and ammonia levels to indicate "fishiness". Microbiological analyses were done on all samples by Silliker Laboratories. A trained panel was constituted at Davis for organoleptic evaluation.

The results were very encouraging. Both levels of carbon dioxide employed were effective in inhibiting microbial growth, and in reducing deleterious chemical changes. Samples stored in such atmospheres were of significantly better quality than the controls. For example, salmon steaks stored in elevated carbon dioxide atmospheres for three days could not be distinguished by the panel from fresh ones taken the morning of the evaluation, while samples stored in air for a similar three-day period could be detected without fail by the panel. Carbon monoxide was not needed to maintain color quality in the salmon, but was effective in the red snapper samples in improving color, particularly at longer storage times (7-14 days). The results suggest a good potential for commercial application.

In a related study, efforts were made to determine the effect of modified atmospheres upon histamine formation by bacteria. Histamine has been implicated as a possible cause of "scombroid poisoning" in certain species of fish, including tuna and mahi-mahi. It has been demonstrated that species of bacteria isolated from spoiled tuna could produce histamine from histidine in a model system. Using a similar system, experiments have shown no inhibition of histamine formation by a strain of *Proteus morganii* in an atmosphere containing 50 per cent carbon dioxide, compared to controls grown in air.

Edible coatings for fish products

A number of products have been suggested for use as edible coatings on fish products that presumably would decrease moisture loss and maintain better quality during storage. One such product (Flavor-Tex) is an alginate gel that provides a mechanical barrier when applied; however, detailed studies of its benefits, particularly on frozen products, were not available. Consequently, we have studied the use of this material on salmon steaks and rock cod fillets held in frozen storage.

Samples were coated with the Flavor-Tex preparation, and controls were either given an ice glaze (containing ascorbate as an antioxidant) or untreated. The fish were then frozen and put in storage, with samples removed at intervals for testing. Measurements were made for moisture loss, total microbial counts, hypoxanthine level, trimethylamine content, and extent of lipid oxidation.

The rock cod fillets had an initial moisture content of about 80 per cent. No appreciable change was observed until the second month of storage. At this point, the moisture level dropped in a roughly linear manner, with the largest losses being in the untreated samples. There was slightly less moisture loss in the samples treated with Flavor-Tex than in those with ice glazes. Salmon samples had slightly lower initial moisture levels (about 76 per cent), but all underwent similar losses during two months' storage.

Hypoxanthine levels increased linearly in all tests for both types of fish with no appreciable differences among any of the treatment groups. Levels of trimethylamine were initially low in all fish and have remained so regardless of treatment. According to G. Chang, 100-fold increases in this compound occur with spoilage; fluctuations encountered in our testing have only been three- to fourfold.

There was more lipid oxidation as determined by thiobarbituric acid assay in the untreated samples than in those either treated with Flavor Tex or glazed. There were no significant changes in microbial counts in any samples during storage.

Myoglobin pigments

A determination of the sequence of amino acids in yellowfin tuna myoglobin has been approximately two-thirds completed, and a manuscript detailing these findings is in preparation. This is the only fish myoglobin for which such information is available.

As mentioned in the earlier section dealing with controlled atmospheres, in the presence of high levels of carbon dioxide, darker species of fish undergo an undesirable darkening, due to oxidation of the myoglobin pigment. We have done a number of experiments to determine by what means carbon dioxide enhances the oxidation. Unfortunately none has been particularly successful. If the Food and Drug Administration approves the incorporation of carbon monoxide in such atmospheres, the pigment which is formed, carboxymyoglobin, is resistant to oxidation and there will be no practical problem. At the time of this report, such approval is yet to be made.

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Cooperating Organizations

California Seafood Institute, Research Committee, Sacramento, California

Flavor-Tex, Tampa, Florida

Silliker Laboratories, Carson, California

TransFresh Corporation, Salinas, California

Tuna Research Foundation, Washington, D.C.

Histamine Toxicity from Fish Products

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

In this intercampus project, Olcott, Price, and Brown at UC-Davis have attempted to identify the substance(s) responsible for "scombroid poisoning" by means of bioassay; and Bjeldanes at UC-Berkeley has investigated the role of secondary substances present in toxic fish in increasing the toxicity of histamine. The latter worker has also brought a simple and inexpensive analytical method for potentially important amines to the final stages of development.

SCOMBROID FISH POISONING – Bioassay of Histamine

Spoiled skipjack tuna *(Katsuwonus pelamis)* is known to cause "scombroid poisoning" when consumed. This fish, as well as others in the Scombridae family characteristically contain large amounts of the amino acid histidine in the muscle. During spoilage, this histidine can undergo bacterial decarboxylation to histamine. The symptoms of "scombroid poisoning" resemble those of histamine intoxication and include flushing about the head and neck with accompanying sensations of heat, epigastric burning, thirst and burning about the mouth, headache, and gastrointestinal distress. When histamine is given orally, humans can apparently metabolize it in such a way as to remove its toxic effects. In spoiled fish, histamine levels are elevated, with those in excess of 100 mg/100 g generally being associated with toxicity. This fact, plus the body's normally efficient defense against orally ingested histamine, leads to an apparent paradox. Current schools of thought center around there being other substance(s) in the spoiled fish which: 1) themselves are responsible for the toxic reaction; 2) enhance the toxicity of histamine or 3) provide for a facilitated passage of histamine through the intestinal wall where it is normally detoxified.

To identify the substance(s) responsible would be of great value in helping describe the toxic mechanism present. Bioassay could be the analytical technique to provide the needed answers. The ideal animal would exhibit a distinct reaction (i.e., regurgitation) shortly after consumption of toxic tuna fish. In addition, no reaction would be seen when the non-spoiled fish was eaten, nor presumably would one be seen if histamine were added to non-spoiled fish up to levels equalling the endogenous concentration in the toxic tuna. With this differential reaction as foundation, the toxic tuna could then be separated into various fractions which could be schematically recombined until the presence of the critical substance(s) becomes manifest.

Use of cats, dogs, pigs, and rabbits

Cats, dogs, and Duroc and Yorkshire pigs were screened for reactivity to toxic tuna. These particular animals were chosen because they are known to possess the regurgitation reflex – which was the response chosen for consideration. In addition, white rabbits were tested, as these animals were shown to develop a diarrheal condition with dietary stress (Brooks, personal communication). After the preliminary screening, follow-up studies were run on the Duroc pigs, as they appeared to be the animals most suited to our purposes.

The animals were given meals of the spoiled fish following a 24-hour fast. The Duroc pigs were the only animals demonstrating a reaction to the fish (regurgitation). Follow-up revealed 75 per cent of the Duroc pigs regurgitated after eating the spoiled tuna fish, and 25 per cent after eating a non-spoiled tuna meat to which histamine had been added. Pigs weighing 18–36 kg were more reactive (85 vs. 75 per cent) than the heavier animals.

Based on the present work, dogs, cats, and rabbits were unsuitable for use in the discrimination of the toxic factors in toxic tuna. Pigs did reveal a good response pattern, but it was not universal within the species, nor in the separate breeds.

Use of Japanese quail

Quail were taken at birth and for nine days were fed either a chick starter meal, or a diet based upon 60 per cent freeze-dried spoiled or non-spoiled tuna. The diets were fed alone, or with added histamine and/or putrescine to determine effects on weight gain. Histamine in the chick starter meal resulted in depressed weight gain while the

putrescine had no apparent effect at the level used. The diets based upon 60 per cent freeze-dried spoiled tuna significantly depressed weight gain when compared to the non-spoiled diets. This was the case even when histamine was added to non-spoiled tuna diets at levels equalling and exceeding that in the spoiled fish. The birds could be valuable for isolation and identification of toxic factors in canned spoiled tuna.

Use of Daphnia

Daphnia (small freshwater crustaceans) were subjected to varying concentrations of aqueous extracts from three lots of commercial canned tuna. Two of the lots contained high histamine levels, having been identified as causing "scombroid poisoning." The third was a control lot of store-bought tuna. The extract of the fish was used alone or with the addition of histamine at levels equalling or exceeding the histamine concentrations in the other two lots. Twenty *Daphnia* per group were exposed for 60 minutes; responses (loss of activity or infrequent twitching) were recorded at 10-minute intervals. Response increased with time, and was dependent upon the concentration of histamine present – regardless of source. LD_{50}'s for the various time and concentration gradients were done. The method is simple, gives reproducible results and might be useful in quality control testing.

ROLE OF SECONDARY SUBSTANCES; DETERMINATION OF AMINES – Research at Berkeley

By the end of the first year of work on this project it had become clear that substances in addition to histamine play a role in scombroid fish poisoning. Thus, for the second year our major objectives were (1) to determine the degree to which certain secondary substances present in toxic fish increase the toxicity of histamine, and (2) to develop a convenient analytical methodology for the secondary substances. Considerable progress has been made toward the accomplishment of these objectives.

Several compounds have been reported to increase the biological activity of histamine in laboratory animals. Of these substances, putrescine and cadaverine occur in appreciable quantities in toxic fish and, in low levels, in nontoxic fish. Putrescine does not appear to play an essential role in the enhancement of histamine toxicity in fish poisoning. Studies with guinea pigs have shown that administration of very large amounts of putrescine, 40 minutes prior to that of histamine, is required for enhancement of toxicity. Our work dealt with the effects of cadaverine on histamine toxicity in the guinea pig. Cadaverine dihydrochloride by itself showed a relatively low toxicity ($LD_{50} \sim 1000$ mg/kg) with a relatively high minimum lethal dose (>500 mg/kg) Simultaneous administration of a low dose of histamine (150 mg/kg), which causes no deaths when administered by itself, with relatively low doses of cadaverine led to a marked increase in toxicity. A dose of 150 mg/kg histamine and 50 mg/kg cadaverine produced approximately 50 per cent mortality. This effect cannot be accounted for by simple addition of toxicities and reveals a definite enhancement (potentiation) of histamine toxicity by cadaverine. These results are consistent with the hypothesis that scombroid poisoning is caused by the simultaneous consumption of histamine and cadaverine in toxic fish. Further work with guinea pigs is in progress to test this notion and to establish the biochemical mechanism of the observed potentiation.

A simple and inexpensive analytical methodology for potentially important amines in fish is in the final stages of development. It utilizes two-dimensional cellulose thin-layer chromatography (tlc) of acidic fish extracts. Spots are visualized by spraying the plates with ninhydrin. The quantities of amines present are determined by elution of the appropriate regions of the tlc plate and comparison of the resulting absorbance with that of standard solutions. The method is useful for determining in a single analysis concentrations of histamine, putrescine, cadaverine, spermidine and spermine, which occur in toxic or decomposed fish.

Publications

Schutz, D., Rapid assay of histamine in tuna and potentiation of histamine toxicity by diamines. M.S. thesis, 1976.

Cooperating Organizations

The Star Kist Tuna Company, Terminal Island, California.

Methods for Quality Assessment in Fishery Products

Berkeley
R/F-23

George W. Chang

The major objective of this research was the development of more convenient ways of detecting spoilage in seafoods. Efforts were directed at the detection of hypoxanthine (HX), since this substance is a good indicator of seafood quality. There is almost no HX in the muscle of living fish, but after death its level rises and if the fish are kept under adverse conditions it rises at a faster rate. In order to simplify the measurement of HX, a prototype specific electrode has been developed.

Since HX accumulation occurs long before there are any visible signs of spoilage, its measurement can give an early indication of the potential shelf life of the fish. In other words, the HX level in fresh seafood may tell us how close we are to having detectable spoilage.

Development of a test paper for HX

Initially, we aimed at developing a simple test paper for HX. Such a test would not be too precise, but it would provide a quick estimate of the amount of HX in a fish sample. We planned to approach this goal in two ways. First, we would look for a simple method to separate HX from other compounds on filter paper. This might allow us to detect HX by simply looking at the filter paper under an ultraviolet light source. If this approach did not succeed, we would explore the use of the enzyme xanthine oxidase for the detection of HX on the filter paper test strip. The enzyme method is more complicated than our first idea, but it is also much more specific for HX.

We found that the ultraviolet light method worked well with solutions of pure HX but not with fish extracts. Extracts from fresh and spoiled fish appeared approximately identical under the ultraviolet lamp. We then tried using ion-exchange papers to separate HX from other components of the fish extracts. The results were again that fresh and spoiled fish were indistinguishable. We were forced to resort to our second alternative, the use of the enzyme xanthine oxidase.

As we started the xanthine oxidase approach, Rand and his coworkers in Rhode Island published a description of the xanthine oxidase test paper that they had developed. It was very similar to the system we had planned to make, but it had a few drawbacks. We were faced with a problem: Should we try to develop a superior test paper or should we leave the development of the test papers to Rand and concentrate on the development of a simple analytical electrode, which makes possible a much more accurate test for HX? We decided on the latter course.

Hypoxanthine electrode

Oxygen is consumed in the enzymatic breakdown of HX by xanthine oxidase. The amount of oxygen consumed is proportional to the amount of HX present and is easy to measure with a commercial oxygen electrode. We made an HX electrode by combining the enzyme xanthine oxidase with a Beckman oxygen electrode. In developing the electrode we found that: a) The HX electrode is convenient and specific. In preliminary experiments with spoiling fish there was close agreement between HX values determined by the electrode and those determined in a more conventional way. b) The reproducibility of the electrode improves by the inclusion of catalase in the reaction vessel. c) Some attention must be paid to the method of preparing the fish extract. Perchloric acid is convenient, but the perchlorate anion interferes with the assay. For this reason we worked with trichloroacetic acid.

Further plans include refinement of the assay by the use of immobilized enzymes and simplification of the operation of the electrode.

Coordinated Management of the Pacific Coast Salmon Fisheries and the Implications of Extended Jurisdiction

Santa Barbara
R/F-24

A. Wyner, B. Ambrecht, and J. Moore

In March of 1977, the United States Congress approved the Fishery Conservation and Management Act of 1976 (P.L. 94-265). The legislation was in response to an observed inadequacy of fishery conservation and management practices and controls. Drafters of the Act hoped that it would provide a national program for the conservation and management of the fishery resources of the United States – a program deemed necessary to prevent overfishing, rebuild overfished stocks, and ensure conservation. One of the major features of the Act was the extension of U.S. jurisdiction to 200 miles.

The extended jurisdiction of Federal Authority over coastal resources established by this Act has provided both an opportunity for coordinated fisheries management and a responsibility to establish regional fisheries management where only fragmented, state management had been before.

The principal interest of this study-in-progress has been the implementation of extended jurisdiction through the Pacific Regional Fisheries Management Council. Specifically, this interest centers around the Council's development of a salmon fisheries management plan.

This research will observe the manner in which the Pacific Council arrives at its policy decisions by articulating the problems facing the resource, soliciting the participation of affected interest groups, and coordinating the activities of scientists, industry representatives and other regulative agencies. These observations, combined with extensive interviews, will provide the basis for evaluating the political and administrative feasibility of the regional council management scheme.

This study is being conducted in two phases. The completion of the first phase (September, 1976 – August, 1977) involved three major efforts:

1. Developing a comprehensive history of salmon management in the context of U.S. fishery management in general.
2. Discerning the major issues of Pacific coast salmon management.
3. Monitoring the implementation of extended jurisdiction in the genesis of the Pacific Regional Fisheries Management Council.

During the second phase of the project (September, 1977 – August, 1978), we will continue to monitor the activities of the Pacific Council, work towards evaluating the capacity of different management schemes to achieve specified policy goals, and appraise the political and administrative feasibility of implementing alternative management schemes.

Cooperating Organizations

All-Coast Fisherman's Marketing Association, Charleston, Oregon

Departments of Fish and Game, California, Oregon, Idaho and Alaska

National Marine Fisheries Service, Seattle, Washington; Washington, D.C.; Portland, Oregon; Terminal Island, California

National Oceanic and Atmospheric Administration, Office of Sea Grant, Washington, D.C.

Northwest Indian Fisheries Commission, Shelton, Washington

Pacific Coast Federation of Fisherman's Associations, Sausalito, California

Pacific Marine Fisheries Commission, Portland, Oregon

Pacific Regional Fisheries Management Council, Portland, Oregon

University of Washington, Institute of Marine Resources, Seattle, Washington

Washington Department of Fisheries, Olympia, Washington

Washington State Commercial Passenger Fishing Vessel Association, and the Sports Fishing Institute, Olympia, Washington

Socio-Economic Aspects of Expansion of the California Swordfish Fishery

Suzanne Holt

The California swordfish fishery has witnessed rapid expansion since 1971, from 55 vessels to well over 450 in 1975. This expansion was due in part to a ban on imports of swordfish. At the same time, spotter aircraft were re-introduced to the West Coast, with a significant effect on vessel catch rates. It has been the purpose of this study to assess the important socio-economic factors giving rise to the fleet expansion and to determine the cost-effectiveness of spotter aircraft.

The swordfish fishery offers a prime example of what is known as a common property resource. When fishers have free access to an unowned resource like swordfish, the incentive is for too many vessels to catch fish too rapidly. With the cessation of foreign imports as a result of FDA regulation on the mercury content of swordfish, the domestic demand for California-caught swordfish exploded. Vessels were rapidly converted from other commercial fisheries and from sportfishing to swordfish fishing, while ex-vessel prices for swordfish rose steadily. In a setting of rapid fleet conversion and rising demand, data are needed to answer important questions. Is the fleet expanding too rapidly, causing average vessel catch rates to decline? Are too few spotter aircraft in use, thereby artificially depressing vessel catch rates? Or, are too many spotter aircraft in use, depressing vessel catch rates and fish population, at a cost which might drive many vessels out of business?

Field surveys of swordfish fishery provide cost estimates and geographical distribution data of fleet

Because swordfish are highly migratory through the warmer waters of the eastern Pacific Ocean and because of incomplete biological data on swordfish, it is currently difficult to determine whether the stock is being overfished biologically. However it is possible to determine if profits in fishing are being dissipated by excessive fleet size and fleet activity. Using a fleet-wide mail questionnaire of the 1975 fleet (the last year for which the use of spotter aircraft was allowed) and intensive field surveys of a random sample of the fleet, vessel costs in swordfishing were compared to revenues, with evidence of excess capacity. Using questionnaire and survey data, costs were estimated for a variety of categories (e.g., fuel, crewshare, galley) for seven different classes of vessels. In addition, field survey and commercial license data were examined to determine the geographic distribution of the fishing vessels across California ports.

It had been hoped that questionnaire and survey data could be generated on the distribution of fresh swordfish to fish markets, restaurants, grocery stores and out-of-state markets. However, the lack of cooperation on the part of the respective wholesalers and retailers made this impossible.

Anonymous logbook data provided by the California Department of Fish and Game made possible statistical analysis of the significance of effort variables (e.g., days of fishing), vessel characteristics (e.g., length, horsepower), environmental conditions (e.g., water color and temperature), and new gear technologies (i.e., spotter aircraft) on vessel catch rates. This analysis gave further confirmation to the evidence of excessive fleet size and activity. It also represented additional spotter aircraft use as a small but significant contribution to catch rates at the 1975 level of activity, while additional days of fishing made significant and large contributions. Given more information on the extent of congestion among spotter aircraft and vessels in 1975, the congestion costs of aircraft use might outweigh their marginal contribution to vessel landings.

Publications

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Cooperating Organizations

California Department of Fish and Game, Long Beach, California

California Fish and Game Commission, Sacramento, California

Commercial fishermen's associations

Social Science Research Lab., San Diego State University, San Diego, California

Comparative Analysis of the Social and Political Systems of the Tuna Fleet of San Diego and Ensenada

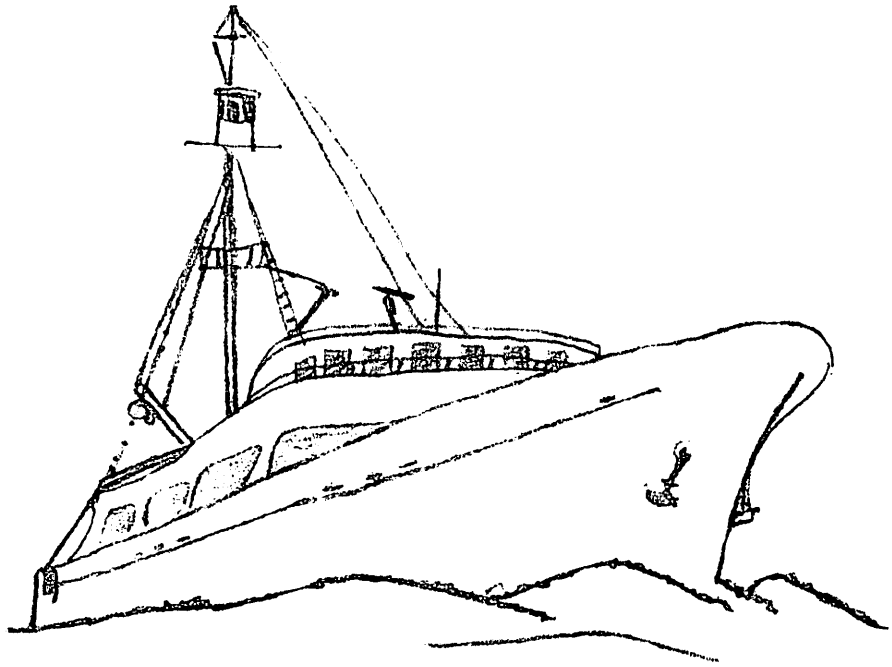
San Diego
R/F-30

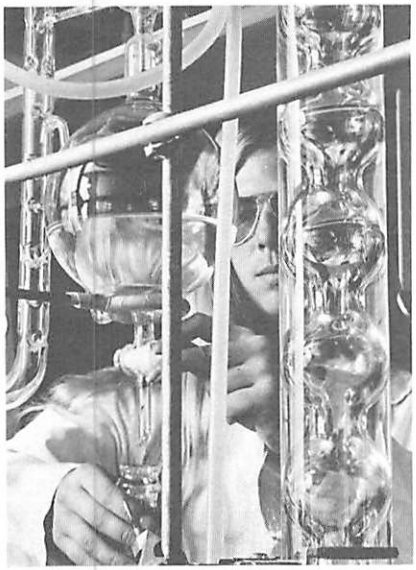
Roy D'Andrade

During the first 12 months of the project our principal concern has been to obtain social and political data relevant to the tuna fleet of Ensenada. The focus of our interviews has been on the elements which contribute to the establishment of restrictive regulations concerning the access of foreign nationals to the territorial waters of Mexico. What are the values or principles that contribute to the institution of restrictive fishing regulations?

We have also examined how decisions are formed at the level of the cooperative federation, the fishermen's union and within the government-operated fishery, and how they are communicated to higher government agencies.

Preliminary findings indicate that individuals in particular structural positions (e.g., the president of the regional federation, and government representatives within the government-operated fishery) provide the principal input into policy-making levels. This input, because of the division of the industry into cooperative fishing boats, private boats, government boats, and boats of foreign registry which pass Ensenada to obtain crew members, may not reflect the actual interests of the majority of the fishermen. The unanimity found among U.S. fishermen on particular issues (e.g., territorial limits, porpoise rules and sanctions) is not generally found among the Mexican fishermen. Thus, directives that result from government policy decisions are likely to favor one group's interests at the expense of another's.





NEW MARINE PRODUCTS

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

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

At UC-Berkeley, efforts are under way to assay for the presence of antiviral activity in marine algae collected from local habitats. Thus, it is hoped to develop therapeutic agents active against viral infections such as herpes simplex in humans. At UC-Santa Barbara, biologically active substances isolated at Scripps from a variety of marine organisms are being evaluated from a pharmacological point of view. Thus far, interesting leads have been obtained for a number of these substances.

Seaweed Products: Applications in Algae Control, Mariculture and Agriculture

William H. Fenical

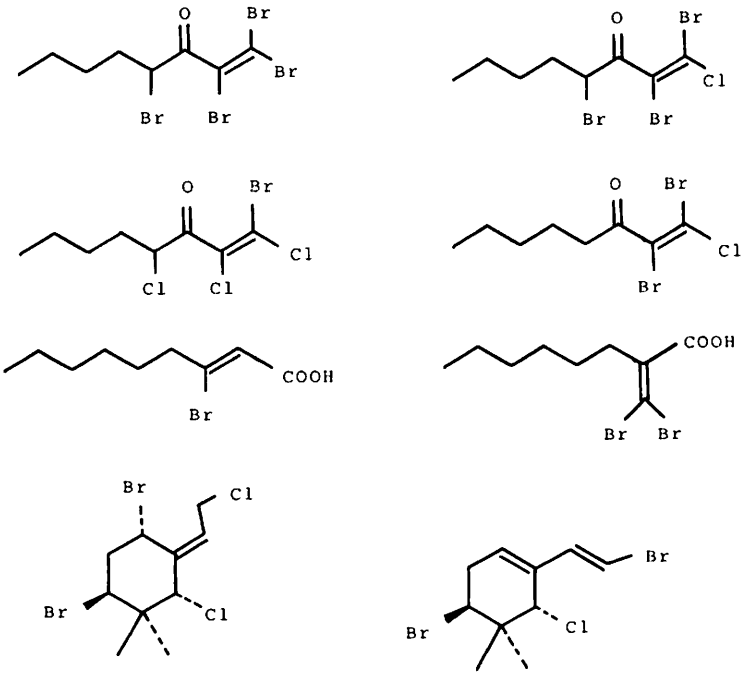
In this three-year project, dedicated to the development of new applications for marine natural products, we explored: algae-inhibiting compounds for antifouling agents, antibiotics for the control of marine pathogens under mariculture conditions, and marine products as new environmentally safe agricultural chemicals. Promising leads were uncovered for developing marine antibiotics and new agrichemicals. On the other hand, development of algicides from marine sources was deemed less fruitful.

Antialgal compounds from marine organisms

A bioassay to detect antialgal activity was devised using several diatoms, among them *Skeletonoma costatum*. In total over 120 extracts and purified chemicals were assayed and their growth inhibition was measured. Our data indicate that most marine extracts contain growth-promoting rather than growth-inhibiting substances. Growth rates of *S. costatum* were doubled in many experiments by the addition of 3-5 ppm of the respective extract. At higher doses growth inhibition did occur, but these results did not stimulate a subsequent isolation program since the molar activities were quite low.

Antimicrobial compounds for mariculture disease control

Antibiotic agents were discovered from over 10 species of seaweeds, and from several invertebrates, which were of potential use in controlling marine pathogens such as *Vibrio* species. This past year several interesting and active compounds have been isolated from *Bonnemaisonia asparagoides*, *B. nootkana* and other seaweeds. These compounds have been structurally elucidated as shown below and confirmed to be potential commercial agents with activities in the range of existing products. Syntheses for the acyclic compounds above have also been devised, to prepare gram quantities for thorough biotesting. Another compound, which is a potent antibacterial agent has been isolated from the local brown alga *Zonaria farlowii*. We have not yet been able to elucidate the structure of this compound but it is closely related to linolenic acid. The many positive results gathered over the past few years indicate this to be a promising area for future development. Several of our

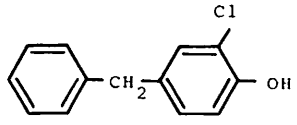


antimicrobial agents have been incorporated into shrimp diets under culture conditions, with apparent reduction in pathogen problems.

New halogenated compounds for agricultural applications

During this grant it has become clear that marine-derived natural products have good potential to provide new chemicals for use in agriculture. This has become particularly obvious with respect to the natural halogen-containing compounds from seaweeds and sponges. For years industrial chemists have designed insecticides and herbicides, incorporating mainly chlorine into those structures and these compounds have generated severe environmental problems.

Over the past year, the progress made has been in the isolation of a variety of new compounds from several sources. Our program has been expanded to include several invertebrates and some of the phytoplankton. Approximately 30 new compounds have been isolated this year. We have just found, for example, that the blue-green unicellular alga *Anacystis marina* produces the monochlorophenol below. This compound is easily



synthesized and is now being rigorously biotested.

One of our goals for the past year has been to continue to develop the potential of elatol as an insecticide. In that regard we made massive collections of several *Laurencia* species and isolated 75 grams of the compound. A chemical modification program is now under way in hopes that a derivative or piece of the molecule will show even more promising results.

Earlier we submitted 3,5-dibromo-4-hydroxy-benzaldehyde, a natural product from *Odonthalia*, for biotesting. This compound showed good herbicidal activity against mustard and several other plant pests. More importantly, this phenol exhibited a protective behavior against "wilt" when mixed with currently used herbicides. We are exploring this behavior currently.

Publications

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Wratten, S.J., W. Fenical, and D.J. Faulkner, Ptilosarcone, the toxin from the sea pen *Ptilosarcus gurneyi, Tetrahedron Lett.*, 1559-1562 (1977).

Cooperating Organizations

Stauffer Agricultural and Chemical Company, Mountain View, California

Marine Natural Products Chemistry of Fouling Organisms

San Diego
R/MP-10

D. J. Faulkner

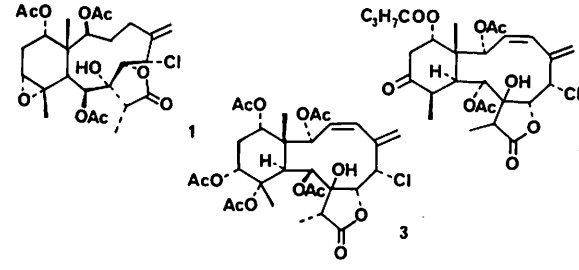
The structures have been elucidated of the major toxins from two sea pens, of four novel pregnane derivatives from a soft coral, and of an unusual antibiotic from a sponge.

Marine natural products chemistry has experienced explosive growth during the past five years and reached a stage where many chemotaxonomic relationships have been established. While reviewing the field of marine natural products chemistry (Faulkner, 1977), we found that a few genera had been studied with disproportionately great intensity. We therefore proposed to study those organisms that appeared to have been largely neglected. In particular, we chose to study fouling organisms because these organisms might use chemical or biochemical methods to compete for substrate.

We soon discovered why there was so little prior research on the chemistry of fouling organisms. It is extremely difficult to obtain a sufficiently large collection of any single species from a pier piling or pontoon. In the few instances where we collected tunicates or sponges from these environments, we were unable to find any interesting metabolites by means of either bioassays or chemical screening.

Toxins from two sea pens

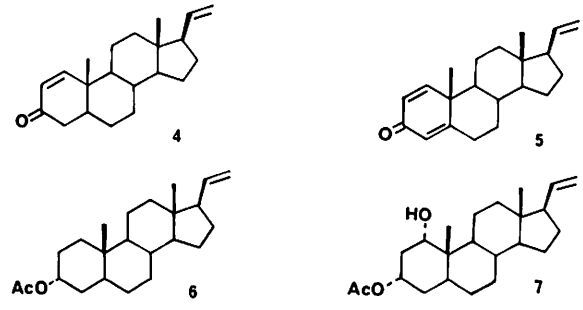
The toxicity assay using *Tisbe furcata* could be employed to detect the toxic components of the sea pens *Ptilosarcus gurneyi* and *Stylatula* sp. and required much less material than the traditional mouse assay. Stylatulide (**1**) was shown to be toxic to *Tisbe* at concentrations (LD_{100}) greater than 0.5 ppm in filtered seawater. The structure of stylatulide (**1**) was determined by X-ray analysis (Wratten, Faulkner, Hirotsu, and Clardy, 1977). A toxin had previously been isolated from *Ptilosarcus gurneyi* by Dr. J. C. Wekell, National Marine Fisheries Service, Seattle. We were able to elucidate the structure of the toxin, ptilosarcone (**2**), by comparison of spectral data with those of stylatulide (**1**) and briarein A (**3**), a metabolite of *Briareum asbestinum* (Wratten, Fenical, Faulkner, and Wekell, 1977). These two toxins, stylatulide (**1**) and ptilosarcone (**2**) were the first natural products obtained from sea pens.



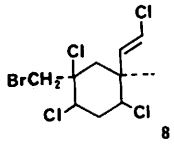
Pregnane derivatives from soft coral

Soft corals and sea pens are both members of the phylum Coelenterata. We have isolated a number of interesting compounds from soft corals collected at Canton Island. Although it is most unusual to find steroids as major secondary metabolites of marine organisms, we obtained four pregnane derivatives **4**–**7** from an unidentified soft coral (Higgs and Faulkner, 1977). The structures of the steroids have been determined by chemical interconversions to a known steroid. The major constituent **4** is being screened for anti-progestational activity by Dr. Marvin Karten at the National Institutes of Health. These steroids had not been encountered previously as either natural or synthetic compounds.

The research on halogenated monoterpenes from *Plocamium* species, originated by Jon Mynderse when he was a Sea Grant trainee, has continued to be of interest. We have recently revised the structure of violacene-1 (**8**) as a result of X-ray analysis (Van Engen *et al.*, submitted to *Tetrahedron Lett.*). The original structure **9** had been assigned on the basis of mass spectral analysis. The X-ray analysis showed that the positions of halogen atoms may be located most accurately using



^{13}C nmr correlations and that the stereochemistry of these molecules may be assigned using the lanthanide-induced shift method.



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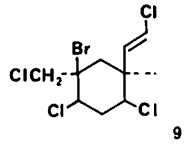
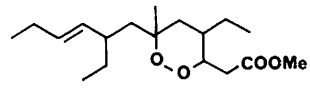


9

Strong antibiotic from sponge

During the last few months of the project, we began collecting compounds for the 1977 project which promised to be of much greater value. We have identified some potential pharmaceuticals from marine organisms, including a strong antibiotic from an unidentified sponge collected at Panama (San Blas Islands). The antibiotic appears to be a cyclic peroxide **10**. The structural elucidation was based on extensive chemical degradations, but



10

many of the reactions must be regarded as abnormal. Prior to the beginning of the new research project, we sent four pure compounds to Dr. Robert Jacobs for pharmacological screening. Two compounds are reported to show interesting activity.

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Marine Plants as a Source of Insect Growth Inhibitors

Phillip Crews

This research is exploring the potential of seaweeds as a source of new insect control agents. Our continuing thrust involves the identification of natural products from the red algae Plocamiceae, which have shown, in crude form, control against several destructive insect pests.

During the period September 1976 to August 1977 this program received only minimal support in the form of a Sea Grant Traineeship to Mr. E. Kho-Wiseman. However, this research was able to build upon results from his thesis project, a study of toxic metabolites from *Plocamium*; consequently reasonable progress was made toward the project objectives.

Two years ago we discovered that species of *Plocamium* including *P. violaceum* Farlow displayed potent activity against three insect pests as shown in the Table. This work was initiated with cooperation from the Zoecon Corporation of Palo Alto, California. A major activity during the past year consisted of examining the active extracts of *P. violaceum* for both major and minor natural product constituents. Several compounds including Plocamene A (**1**), Plocamene B (**2**), and Plocamene E (**3**) were isolated, characterized and tested. As can be seen in the Table, the assay activity for each of these compounds does not match the level of potency displayed by the crude extract. Our continued search for the active principle has yielded at least four other cyclic monoterpenes which have been characterized. They have been forwarded for testing.

Acyclic monoterpenes from *P. violaceum*

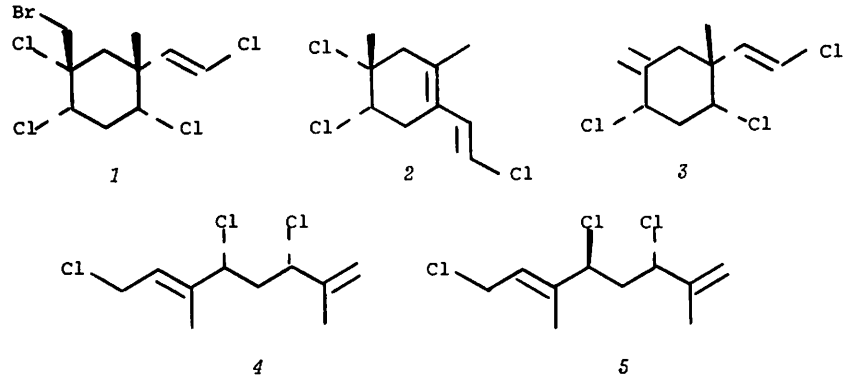
We have explored the natural products from *P. violaceum* from a number of locations in central California in order to maximize our encounter with the major and minor products. This is a fruitful approach because at least

INSECT-CONTROL ACTIVITY OF ALGAL EXTRACTS AND PURE COMPOUNDS AGAINST INSECT-SENSITIVE SYNCHRONIZED INSTARS[a]

Run	Composition	Source	Spider mite eggs, *Tetranychus urticea* (% conc.) IC_{50}	Mosquito, *Aedes aegypti* (ppm) IC_{50}	Fly, *Musca domestica* µg/prepupa ID_{50}
E	Crude extract	*P. viol.* (4-mile)	0.1	0.01	78
H	Plocamene-A	pure	>0.1	>1.0	65.0
I	Plocamene-B	pure	>0.1	0.05	
J	Plocamene-E	pure		>0.1	>100
K	Standard insecticide	BHC (Zoecon Co.)		0.14	0.3
L	Standard insecticide	DDT (Zoecon Co.)		0.05	>100

[a] ID_{50} or IC_{50} values (dose or concentration) required to produce 50% metamorphosis.

two chemical types of *P. violaceum* exist. From this survey we have discovered a new set of acyclic monoterpenes including (**4**) and (**5**). These compounds are unique in that they



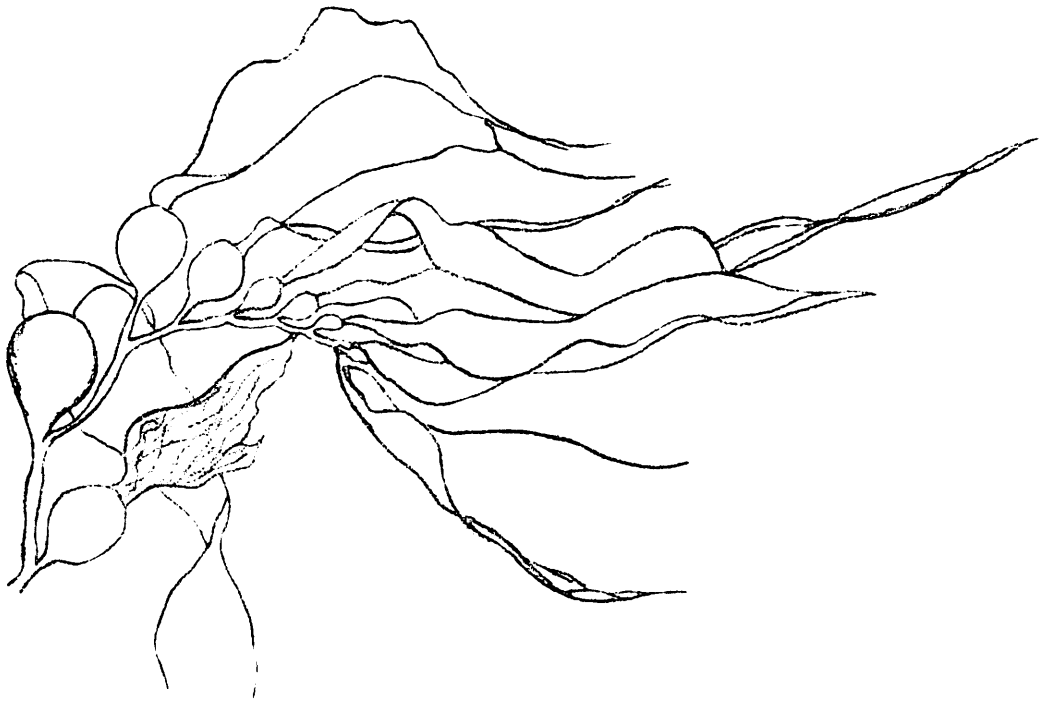
are the first acyclic monoterpenes we have encountered from this species. They also appear to be the biosynthetic precursors of the acyclic types such as (**1**)-(**3**). Testing for insect control activity on these compounds is now in progress. When these various data become available, we will be able to interpret more fully the promise of results in the Table for the extracts of *P. violaceum* as well as similar data that we have collected for other *Plocamium* species.

Publications

Crews, P., E. Kho-Wiseman, Acyclic polyhalogenated monoterpenes from the red alga *Plocamium violaceum*, *J. Org. Chem.*, **42**, 2812 (1977).

Cooperating Organizations

The Zoecon Corporation, Palo Alto, California



Tissue Culture of *Macrocystis* and Related Seaweeds of Economic Importance

William H. Fenical and Ralph A. Lewin

This project is aimed at isolating and purifying single cells from macroalgae, which are important producers of commercially used polysaccharides, and to explore the potential for mass scale tissue culture.

The main factor determining the techniques used in this project was the necessity that the cultures be axenic. If bacteria were present in the cultures they would either outgrow the *Macrocystis* or feed upon it. Since a several-month period is likely to be required for algal growth to be observed and its characteristics documented*, non-axenic cultures could become enrichment cultures for agar-digesting bacteria.

The culture medium initially selected was a seawater medium enriched with vitamins and nutrients:

KNO_3	50 mM
KH_2PO_4	5 mM
B_{12}	1 µg/l
biotin	1 µg/l
thiamin	10 µg/l
EDTA	5 mg/l
trace metal mixture	1 ml/l

In addition, varying concentrations of soil extract (0-100 ml/l) and indole-acetic acid ($0\text{-}10^{-4}$ g/l) were added.

Beach-cast blades were used in the first attempts to culture *Macrocystis*. These blades were, however, so permeated with bacteria that surface sterilization of these tissues was unsuccessful. It was evident that freshly collected material would be required for further studies.

Freshly collected *Macrocystis* blade tips were surface-sterilized in 10 per cent bleach solutions for 5-30 seconds. After a rinsing with sterile seawater, the tips were homogenized in a sterile blender container in a 5 mg polyvinyl pyrrolidone/ml seawater solution. Aliquots of the macerated blade tissues were pipetted into test tubes containing sterile medium. The tubes were incubated at 15°C in a light room and screened for bacteria after approximately two weeks. Several hundred specimens were treated in this manner and after three months, 60 per cent of the sterile blade pieces showed no pigment decomposition — evidence that, although no actual growth was observed, tissue integrity was maintained.

Failure of the blade pieces to grow was attributed to the lack of an abundance of meristematic tissue. Culture experiments were next initiated using the growing tips of *Macrocystis* haptera in the hope that these tissues would provide more cells capable of growth.

Pretreatment of haptera

The haptera, broken into small pieces, were surface-sterilized in 10-20 per cent bleach for 5-60 seconds. They were then rinsed in sterile seawater and the growing tips were sliced off in 1-5 mm pieces. The tips were transferred to agar plates of the seawater medium containing 1 g/l yeast extract. After a few days, pieces free of bacterial contamination were transferred to fresh agar plates. The tips that remained sterile were transferred in 4-14 days to tubes of the liquid seawater medium and incubated at 15°C in a light room. Some of these tips have been in culture for two months. As yet no growth has been observed.

The experiments with *Macrocystis* to date suggest that it is possible to maintain this alga in a liquid medium. In these experiments the alga was exposed to constant illumination. It may be found in future experiments that a more natural 12 hr-12 hr light-dark regime is more conducive to growth. The possibility of culturing other species of brown algae should be explored; and to this end, work has been recently begun with *Ectocarpus*.

Cooperating Organizations

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

*Fagerberg, W. R., and C. J. Dawes, *Am. J. Bot.*, 63(1), 110-119 (1976); Markham, J. W., *Syesis*, 1(1-2), 125-131 (1968).

Development of Antiviral Compounds from Marine Algae

Neylan A. Vedros

This study evaluated the prophylactic and therapeutic potential of anti-herpes virus material in extracts from marine red algae (family Dumontiaceae), gathered from intertidal coastal areas of northern California. Using the mouse encephalitis and dermatitis models, we have shown that the algal material interfered with virus replication under defined conditions. The chemical nature of the active component appeared to be a sulfated polysaccharide, uniquely different from other sulfated algal polysaccharides. The results to date suggest that this marine resource may provide a useful product for treatment of herpes infections in man.

Our major efforts during the past year have been directed primarily: (*i*) to extend present knowledge beyond the finding that anti-herpes virus components in extracts from eight related species of marine red algae (family Dumontiaceae) are structural polysaccharides and (*ii*) to continue evaluation of the prophylactic and therapeutic potential of the algal polysaccharide in herpes virus infections by use of various laboratory animal model systems. Our results to date on chemical characterization indicate that lipids were probably not present in the extracts, because the viral inhibitor was not partitioned into common lipid solvents. Some protein was present, albeit in small quantity, as the active component was extractable in phenol. Also, addition of pronase to partially purified extracts diminished the antiviral activity. On the other hand, the additon of DNase and RNase to these extracts produced no noticeable effect, thus eliminating nucleic acids as being important in the stucture of the viral inhibitor. The observation that concanavalin A formed an insoluble complex with antiviral molecules was indicative of the presence of α-D-glycosyl and sterically related residues in the branch chain polysaccharide molecule. Chemical analysis (carried out by Donald Renn at Marine Colloids, Inc.) of partially purified material from *C. simplex* showing antiviral activity indicated the presence of sulfate (20 per cent) in the ester form. In general, there seemed to be approximately one ester sulfate for every two hexose moieties, and a mere scattering of pyruvate (one for every 35 to 40 hexoses).

Tests on other sulfated polysaccharides

Inasmuch as the antiviral substance appeared to be sulfated polysaccharide(s), it was of interest to establish if other selected sulfated polysaccharides, such as kappa, lambda, and iota carrageenans and some unialgans (purified by Marine Colloids, Inc.) were also active against mammalian viruses in cell culture, including herpes simplex virus. The purified by Marine Colloids, Inc.) were also active against mammalian viruses in cell culture, including herpes simplex virus. The purified polysaccharides showed a wide antiviral spectrum in contrast to our unpurified algal material which was active only against herpes virus. The polyanionic nature of the algal antiviral material was subsequently confirmed by data from comparative studies with other polyanionic material (i.e., heparin and dextran sulfate), which indicated that diethylaminoethyldextran effectively removed the antiviral agent from liquid suspensions.

We still have no explanation for the restricted specificity of action of our antiviral material for herpes viruses. However, this may be an indication of some uniqueness in the molecular configuration distinguishing it from sulfated polysaccharides from other sources which were capable of interfering with the replication of a variety of viruses. The observation that the antiviral activity of our material precipitated in the presence of concanavalin A promoted some interest in future tests with other lecithins to establish the nature of specific intermolecular linkages. It is also considered important to progressively remove sulfate groups from the polysaccharide and assess their influence on antiviral action.

In vivo tests of the antiviral material

The inhibitory effect of the antiviral material *in vitro* was determined *in vivo* in the encephalitis mouse model. Primary and secondary extracts from marine algae, earlier shown to have anti-herpes virus activity in

cell culture, protected infant mice from lethal encephalitis initiated by herpes simplex virus (type I and II), provided the inhibitor was administered prior to or at the same time as virus. No protection occurred when extracts were given in a single dose as little as 2 hours after virus. This supports earlier evidence from *in vitro* studies suggesting that the antiviral substance acts by blocking an early step in the adsorption of virus to otherwise susceptible cells. However, preliminary results from independent investigators associated with the National Institute of Allergy and Infectious Diseases (Earl Kern and Lowell Glasgow) indicated some therapeutic efficacy when multiple doses of extract were administered to infected mice.

Results of studies evaluating the ability of the antiviral material to prevent or cure herpes-induced skin lesions in adult mice indicated that this material could prevent but not cure lesions. The chief problems encountered with the animal model related to the nature of the infection and the manner of treatment. The virus in skin lesions was able to spread to uninfected cells without being exposed to the extracellular environment. Therefore, high molecular weight antiviral material, unable to penetrate cell membranes, may have been unable to block the migration of virus to uninfected cells. In addition, treatment with unpurified material meant that insufficient amounts of active substance may have reached susceptible cells in the zone of infection.

During the past year we obtained a more prevalent source of *Constantinea* and *C. simplex* (namely, *C. subulifera*), and showed that it also possessed activity against herpes simplex. We anticipate that this species will adequately serve as a source for large-scale extractions with the eventual preparation of highly purified antiviral material for further testing in our laboratory and elsewhere. Once greater understanding of the nature of the active substance is achieved, it may be possible to reduce molecular size by selective cleavage, thus permitting its administration in therapeutic trials by intravenous, intramuscular or oral routes. Until more purified material beoomes available, however, it will be difficult to establish an adequate dose-response relationship for the antiviral material or to critically define its mechanism of action.

Publications

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Hatch, M.T., D.W. Ehresmann, E.F. Deig, and N.A. Vedros, 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 IXth International Seaweed Symposium, Santa Barbara, California, 1977.

Cooperating Organizations

Antiviral Evaluation Program, National Institutes of Health, Bethesda, Maryland

Marine Colloids, Inc., Rockland, Maine

Pharmacology Evaluation Program

Santa Barbara
R/MP-15

Robert S. Jacobs

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, acetylocholine, norepinephrine, and other chemicals that occur naturally in the human and are implicated in diseases or in the 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 14 different marine products. To date the tests completed have not revealed the primary biological activity of all 14 substances; however, interesting leads have been obtained for a number of them. In a few cases, striking activity was identified.

Preliminary results

The results that are reported below remain tentative until confirming studies are completed. Our findings thus far are as follows:

1) Dr. Faulkner has submitted five marine products. One compound, isolated from sacrophyton, produced a neuromuscular blockade irreversible in frog sartorius nerve-muscle preparations. Injection in mice produced bizarre neurological sequelae accompanied by increased central nervous system stimulation. In isolated mammalian nerve-muscle preparations, this compound produced effects opposite to those seen in frog muscle preparations.

A second compound Dr. Faulkner isolated from the sea pen produced analgesia in mice (i.e., they did not appear to recognize painful stimuli).

2) Dr. Fenical submitted three compounds isolated from red algae. All three of these exhibited a wide spectrum of activity in a variety of tests. The most specific activity was their ability to inhibit cell division. This action was not evident in any of the other marine products studied thus far.

3) Dr. Crews submitted six compounds. Two compounds appeared to have effects on the heart and to antagonize acetylcholine and histamine.

It is our current objective to pursue the activity of the most interesting marine products studied, with the view to verifying our tentative findings and establishing the novelty of the actions observed. The compound from sacrophyton that blocks frog neuromuscular transmission, the compound from sea pen that produces analgesia and one of the compounds from red algae that inhibits cell division have been selected for these more extensive studies.

ENERGY RESOURCE RESEARCH AND DEVELOPMENT

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

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

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

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

Biological Effects of Waste-Heat Effluents of Coastal Power Plants

Ralph I. Smith and Cadet Hand

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

The following account supplements last year's annual report to cover the completion of studies and the preparation of Ph.D. theses by trainees Brian L. Jennison and Bruce R. Hargreaves, who were granted a six-month extension of support beyond the normal termination date of September 30, 1976.

Study of mussels and barnacles

The project had its origin in studies of trainee Anson H. Hines on the growth and reproduction of mussels and barnacles in the discharge canal of the Pacific Gas and Electric Company's power plant at Morro Bay. It was intended to gain data on the effects of temperature on attached marine organisms in the warm-water discharge canals of coastal power plants. The so-called "waste-heat" resulting from the use of seawater in the cooling systems of such plants, whether nuclear or conventional, has biological effects that must be assessed if reasonable limits are to be set in plant design, to minimize local environmental effects. We need more and better information on the precise effects of the heated effluent, and the several aspects of this project have contributed information on typical representatives of three important groups of attached, intertidal, marine animals: barnacles, mussels, sea anemones, and, indirectly on one starfish.

Trainee Hines started his study in 1972-74 with the support of NSF Grant GI-34932 to Professors G.J. Trezek and V.E. Shrock, College of Engineering, UC-Berkeley. In 1974 Mr. Hines received Sea Grant Support under project R/E-10. He continued his research and was awarded the Ph.D. in 1976.

Study of the common intertidal sea anemone

A second aspect of Project R/E-10 was a study of the common intertidal sea anemone *Anthopleura elegantissima*, by trainee Brian L. Jennison, who was supported under this project from 1974 to 1976. He received an extension until 1977, when he completed his doctoral dissertation. One of his important findings was that *anthopleura* in the heated outfall spawned as much as a month earlier than control populations, but that production of sperm in males in the outfall was delayed, and compressed into a shorter period, suggesting a loss of reproductive efficiency. A possible cause of these effects was seen in lower lipid reserves of outfall sea anemones. Sea anemones grown in cooler control conditions spawned very much earlier when transplanted into the outfall than did the sea anemones that had grown naturally since settlement in the outfall. This suggests that sea anemones in the outfall become acclimated to, or survive selective elimination in, the warmer water. Their lower lipid reserves may result from the higher demand for food imposed by growth in this warmer water.

Energetics and growth of two species of marine mussel

The third aspect of Project R/E-10 was carried out by trainee Bruce R. Hargreaves, who completed his Ph.D. research and thesis in 1977, with support of an extension of this grant. Dr. Hargreaves studied the energetics and growth of two species of the marine mussel genus *Mytilus: M. edulis* of quieter and more brackish bays and estuaries, and *M. californianus* of our exposed open coast. Prior to his support he had been engaged in laboratory investigation of the problem, but Sea Grant support was extremely helpful to him in the later stages. His Ph.D. thesis covers only one aspect of his studies, namely growth as a function of temperature, seasonal, and specific differences. He was able to develop a

mathematical model or set of equations relating growth rate to the tissue weight at the start of observations. As explained briefly in his final report and at some length in his thesis, one exponent describing the weight appears to differ with the species; values describing the rate of growth varied with season. Below 20-22°C, the growth rate appears to be limited by the food available. Above this temperature level, growth of these mussels may be retarded. However, as previously reported, *M. edulis* can thrive in the outfall up to about 25°C, which is warm enough to exclude its major predator, the starfish *Pisaster ochraceus*. This is valuable information for those concerned with setting upper limits on the temperatures allowable in coastal power plant effluents, or in cultivating this potentially economically important food animal.

Instruments for measuring consumption of oxygen and food

Further aspects of Dr. Hargreaves' research, not forming part of his Ph.D. dissertation, included development of a flow respirometer for studying oxygen consumption continuously over long periods, and a food dosimeter which measures the rate at which mussels remove food from the water and which continually replaces the food consumed so as to maintain constant nutritive conditions. The importance of the latter device as a pilot apparatus for developing means of raising mussels and other filter-feeding animals in artificial culture should be stressed – whether for scientific study or for commercial food-growing operations. The work not reported in the Ph.D thesis will be completed and is to appear in separate publications.

Conclusions

Project R/E-10 has contributed sound data on the effects of temperature on the growth of three important and representative types of sessile marine animals able to tolerate the moderately warmed effluent of a typical large coastal power plant. The studies of Hines on barnacles, Jennison on sea anemones, and Hargreaves on marine mussels will be basic to future studies of this sort anywhere in the world, and should be of interest to engineers and environmental protection personnel, as well as to basic marine scientists and those developing methods of growing marine organisms in aquaculture operations.

Publications

Hargreaves, B.R., Growth of two marine mussels, *Mytilus edulis* and *Mytilus californianus*, Ph.D. thesis in zoology, University of California, Berkeley, 1977.

Jennison, B.L., An analysis of the environmental factors which influence gametogenesis, spawning, and nutrient storage in the sea anemone *Anthopleura elegantissima* (Brandt, 1835), Ph.D. thesis in zoology, University of California, Berkeley, 1977.

Cooperating Organizations

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

Stray Electrical Current Hazards to Prestressed Concrete Construction in Seawater

Israel Cornet

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

The main purpose of this investigation is to study quantitatively the effect of dc stray electric currents on the corrosion of steel in prestressed concrete. Thirty prestressed beams (2.5 x 2.5 x 48 in), coated at each end with 9 in epoxy to reduce end effects, were made. The 0.172 in steel diameter was prestressed to 175 ksi ±5 per cent. Beams in either diffuse or concentrated cathode configuration, immersed in synthetic seawater, were subjected to an anodic constant potential test with different times of exposure and at different current densities: 85 mA/sq. ft (eight beams), 60 mA/sq. ft (two beams), 40 mA/sq. ft (four beams), 20 mA/sq. ft (four beams), 10 mA/sq. ft (three beams), 5 mA/sq. ft (six beams), 2.5 mA/sq. ft (one beam), no current (two beams). Visual inspection, resistance and potential measurement were employed to detect the time for steel to start corroding. Tension-to-failure tests determined the reduction in breaking strength. Fifteen beams have thus far been tested to failure; the remaining 15 — seven of which with visible signs of corrosion — are still under test.

A distinction has been made between the time to a change in the anode potential, which is taken as the moment when the steel starts to corrode, and the time to the appearance of the first visible sign of corrosion, such as cracks or rust spots on the concrete surface.

The reduction in breaking strength of the embedded steel has been associated with the localized nature of the corrosion. A model based on Faraday's law yields the breaking strength in terms of the corroded length. Calculated and true corroded lengths agree reasonably well for beams at high current densities and with long times of exposure. A dimensionless parameter based on the time to change in potential and the age at test seems to represent best the distribution of corrosion along the wire. A model of the corrosion process has been made.

Cooperating Organizations
Pacific Gas and Electric Co., San Francisco, California
Port of Oakland, Oakland, California

Earthquake Loading on Large Offshore Structures in Deep Water — A Study for the Correlation of Analytic and Physical Models

Robert L. Wiegel

In this project, a model of an offshore oil storage tank was designed and constructed, which is being used to examine fluid-structure interaction under realistic earthquake conditions.

The trend in recent years in offshore development has been toward larger structures in deeper water. While a large body of data has begun to accumulate concerning the resistance of these structures to ocean wave conditions, very little information is available with respect to their response 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 such structures in many seismically active areas off the West Coast. This program was formulated to assist in reducing the uncertainty associated with earthquake effects on large offshore structures by performing actual measurements of these effects on a scale model under laboratory conditions and comparing these results 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, UC-Berkeley. 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. Byrd and Fukij Nilrat. The experiments are being conducted at the UC Earthquake Engineering Research Center (EERC) at Richmond, California.

Effect of acceleration forces

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, possibly 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.

Importance of model foundation

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 which 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 homogeneous 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 plane of motion.

The structure of the model itself was designed to be an essentially rigid body, since the study was not involved in consideration of structural deformations. The model was made from an aluminum cylinder with 1-in walls and heavily braced internally.

Inertia coefficients

There were several questions concerning the hydrodynamic inertia coefficients considered in this study, the major ones being the magnitudes of the coefficients relating to the principal modes 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 there is significant interference, or coupling if you will, between the various modes of motion insofar as 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.

Scaling of model

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 have led to the model as shown in Fig. 1, which represents a structure of about 34 meters height and 80 meters diameter on a scale of 1:100. This would be the approximate size of a structure in the mass range of about 250,000 tons.

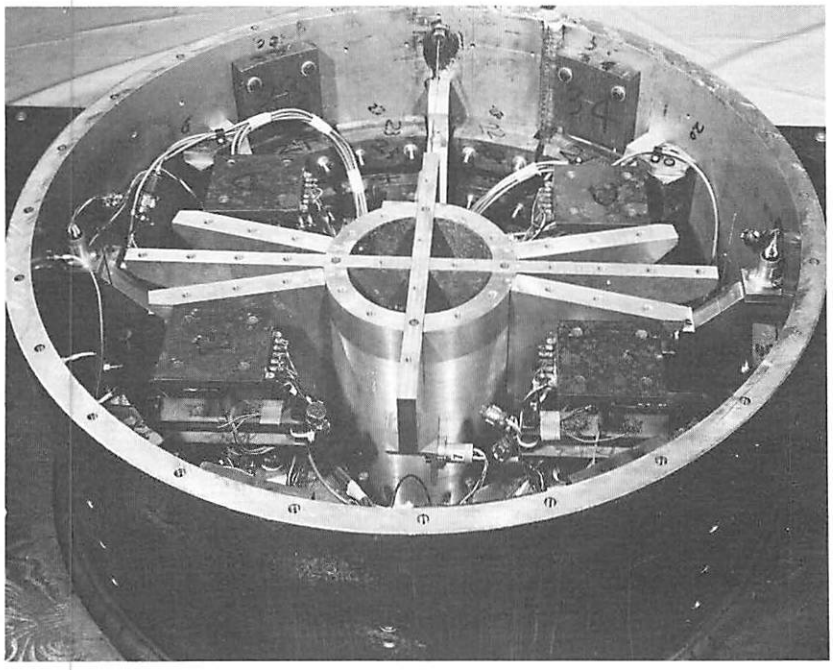


Fig. 1. Completed submerged tank model, with top main cross-support removed, showing internal instrumentation

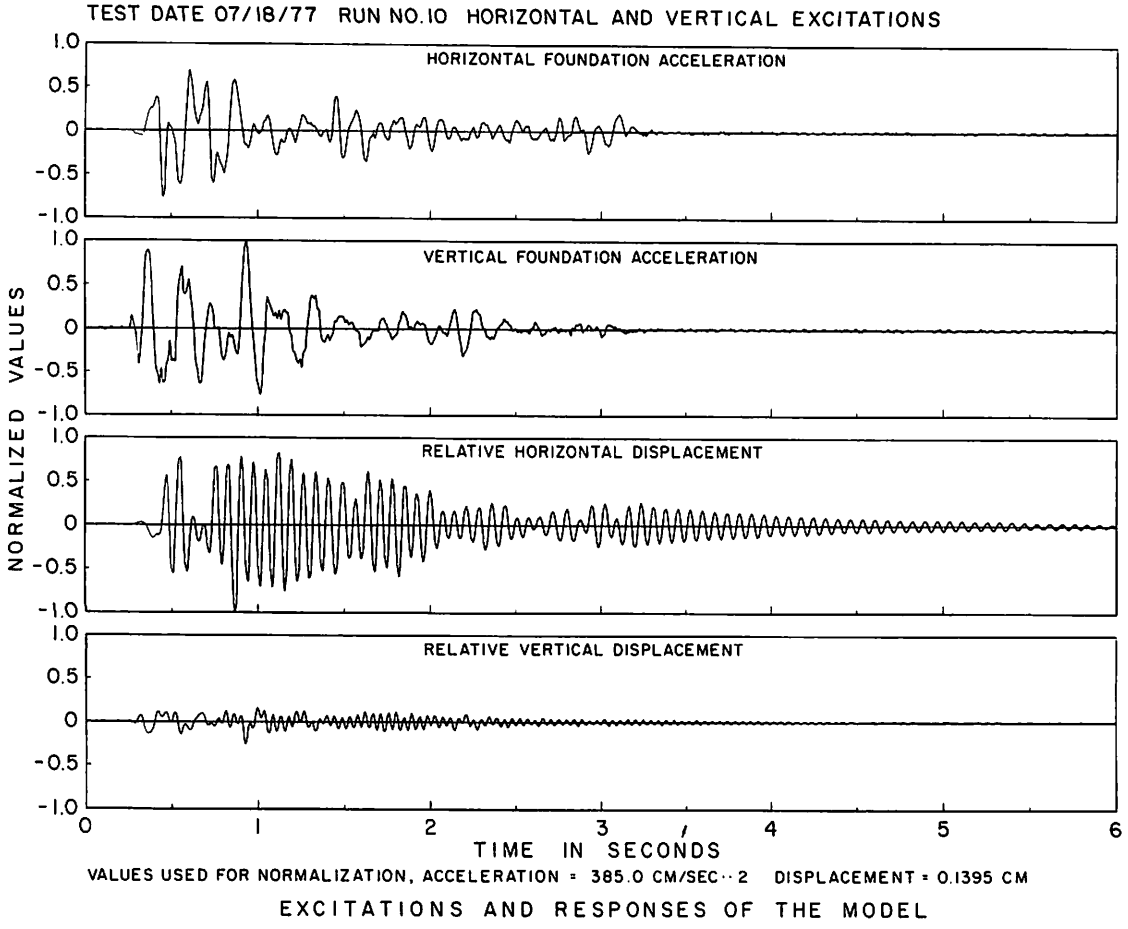


Fig. 2. Typical model response normalized for a reproduction of an actual earthquake ground motion with peak acceleration of about 40 per cent of gravity

Instrumentation

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 also include the capacity to measure model acceleration, foundation forces, and fluid pressure distributions directly. This allowed sufficient redundancy to cross-check the results and enabled better comparisons of response with analytic techniques.

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. These tests were concerned with verifying the dry response of the model and determining the submerged response at the maximum water depth. They 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 per cent of gravity, depending on physical constraints. Reproductions of actual earthquake excitations were also used in each case, with maximum accelerations as high as 50 per cent 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. A typical test result showing normalized ground acceleration and the resulting model displacement is shown in Fig. 2.

Cooperating Organizations

University of California, Earthquake Engineering Research Center, Richmond, California

Seismic Hazards to the Development of Offshore Oil Resources

William A. Prothero

Earthquakes pose a major hazard to structures in California. On land, monitoring of smaller, more frequent earthquakes is accomplished with permanent and portable seismic stations. These measurements provide a positive indicator that a particular fault is active as well as a method for locating previously unknown active faults. Importantly, land-based measurements alone are not sufficient to study the hazards to offshore and onshore installations. Seafloor seismic monitoring must be performed. For large, potentially hazardous installations such as the proposed LNG terminal at Point Conception and the Diablo Canyon nuclear reactor, seismic hazards determinations play a critical role in the site selection process. This project studies offshore faults and their continuation onshore to relate microseismicity to historic seismicity.

Ocean bottom seismometer

The first year of work has been devoted to the design and construction of three ocean bottom seismometer (OBS) capsules to carry out the seafloor monitoring for small earthquakes. A new design for the capsules was required because existing instruments were not suitable for deployments from small vessels (less than 100 ft) and ships of opportunity. The new OBS capsules can be launched without an expensive portable laboratory and can record for periods up to three months. Since much less effort will be required to maintain the capsules, more deployments and thus more data will be obtained for less overall cost.

Oceanographic data acquisition

The instrument also has broad application to oceanographic data acquisition. The microprocessor, digital data acquisition and storage system, and accurate internal time base could be used to record the output from any analog or digital sensor and preprocess the signals or make decisions about whether or not to store them. The list of specifications below describes the OBS characteristics in detail.

Future plans

The completion of the capsules has proceeded more slowly than expected, but we still plan for two to three months of deployment time during the second contract year. The first study areas planned are the eastern Santa Barbara Channel and the southern Hosgri Fault Zone. Studies of eastern Santa Barbara Channel faults relate to hazards to future Channel Islands developments and hydrocarbon recovery operations in the Channel, while the southern Hosgri studies relate to the seismic safety of the Diablo Canyon nuclear power plant and possible development at Point Conception and in the Santa Maria Basin. Funding from the U.S. Geological Survey is being requested to extend our seismicity studies of the Hosgri Fault Zone onto land.

OCEAN BOTTOM SEISMOMETER SPECIFICATIONS

Mechanical	
Weight	136 kg (approx.)
Descent rate	1 m/sec (approx.)
Ascent rate	1 m/sec (approx.)
Pressure Case	
Material	7075 T6 Aluminum
Coating	Hard anodize and dichromate seal
Design depth	6000 m

Release System	Dual explosive bolts actuated by acoustic recall, or two independent timers
Sensors	3 component Mark Products L-25, 4.5 Hz geophones gimbal levelled with solenoid-actuated locking mechanism
Recording System	
Mode	12 bit digital with 9 bits of gain ranging
Tape recorder	Braemar cassette with 4-track head
Data capacity	10^6 samples
Trigger system	microprocessor controlled short term vs. long term average
Data memory	3000 samples
Sample rate	Maximum of 200 samples/sec (all 3 channels)
Timing	Crystal oscillator with internal thermistor for temperature corrections
Power Requirements	0.13 watts (continuous)
Power Source	Gates rechargeable "Energy Cells"
Maximum Design Deployment Time	
Rechargeable battery pack	1 month
Lithium battery pack	3 months
Acoustic System	
Ranging	Sonatech transponder -- accuracy about 3 m
Commands	Release and diagnostics
Diagnostics	Command received, battery voltages, noise level, number of events recorded, tape runtime
Diagnostic code	One ping = "0"; two pings = "1"

Special features and improvements over the previous SIO OBS:

1. All checkout, battery charging, and data playback is done without opening the capsule.
2. It is small enough to fit through a narrow ship's door and is launchable from smaller boats.
3. Assembly time is minimal because of printed-circuit card construction. The mechanical systems are also considerably simplified.

Marine Vehicle Safety Analysis

J. Paulling and W. Webster

An investigation has been made into the possibilities of using the theory of differential games to solve the ship collision avoidance problem. Because of difficulties involved in applying game theory to a nonlinear model, this approach has been abandoned in favor of a previously developed random search technique.

In order to determine the ship trajectories, it is necessary to know certain coefficients in the equations of motion. Use is being made of the results of model tests of a Mariner Class ship carried out under an NSF grant. The tests measured the side forces and yawing moments in deep water for 210 different model configurations consisting of various rudder angles, sway velocities and propeller r.p.m.'s. Analysis of this information has been performed using a CDC 6400 computer. To determine the effect of rapid r.p.m. changes on steering control, the analysis was performed for constant towing speed with the r.p.m. varied about the normal self-propulsion point. Results have shown that the forces and moments on the ship are strongly dependent on propeller r.p.m. as one would expect, and that this dependency is approximately quadratic in nature. These forces and moments have been approximated by a pair of polynomials whose terms involve various powers of rudder angle, sway velocity and r.p.m. The 11 coefficients in each polynomial have been determined by linear regression. In the few cases where comparison with other test results is possible, the correlation is reasonably good.

A computer program to determine ship maneuvering characteristics has been completed. Ship trajectories are computed for seven rudder angles and two speed commands by numerical integration of the equations of motion. The output lists the ship position, heading, speed, drift angle and propeller r.p.m. at five-second time intervals beginning at the time of execution of the maneuver. A plotting routine may be used to generate computer plots of the ship path. The ship trajectories are stored on tape for use by the collision avoidance program.

A collision avoidance program has been written to compute optimal maneuvers as well as critical ranges and times for various collision situations. The program assumes a perfect collision course between two ships with a specified relative bearing. The initial range which allows the ships to just miss each other (the critical range), is computed for each of the possible maneuver combinations based on the predetermined ship trajectories. The combination with the smallest critical range is designated the "optimal" maneuver for both ships. With all the critical ranges known, it is then a simple matter to also compute the worst maneuvers; and likewise, combinations, such as the best maneuver of one ship with the corresponding worst maneuver of the other. The finite size of the ships is taken into consideration by assuming both hulls to have a flat oval shape as described in a previous work by Webster. With the optimal maneuvers and critical ranges determined, it is possible to plot critical range in polar coordinates as a function of relative bearing, thus delineating the danger zone, inside of which a collision is unavoidable. This analysis has been performed for the case of unrestricted maneuvering and for the case of the "right turn rule", in which both ships are restricted from making left turns.

A study has been performed of the effect of radar inaccuracies on the probability of collision and the choice of optimal maneuvers. A normal distribution is used to describe the uncertainty in position of the other ship, and various values of standard deviation are assumed. Under these assumptions it is possible to compute confidence levels for all possible maneuvers and to choose the maneuver with the greatest probability of being correct. One can also compute an expected value for the critical range which is generally different from the value obtained with a perfectly accurate radar. Finally the probability of collision may be computed for various ship positions and standard deviations in positions.

Preliminary conclusions

The results of the maneuvering simulation indicate that while the ship may have a greater

directional stability in shallow water (depth to draft ratio of 1.7) as determined by the linearized equations of motion, the advance of the ship after a 90 degree turn is always less in shallow water according to both the linear and nonlinear solution. This appears to be due to increased rudder effectiveness at this depth which allows the ship to reach its steady state turning configuration more quickly.

The results also consistently indicate that the ship will turn more quickly and have a smaller advance if the power is increased in the turn rather than decreased. This was expected, since the increased propeller r.p.m. increases the flow over the rudder and hence also the rudder effectiveness.

The results of the collision avoidance program indicate that the critical range is always less in shallow water at the depth tested. This is a natural consequence of the increased rudder effectiveness and smaller advance. The best maneuvers almost always include an increase in power in both deep and shallow water and are frequently not the maximum rudder commands.

Confidence levels for maneuver choices were found to drop off rapidly with increasing standard deviation in position, as one would expect. The confidence levels were also found to depend heavily on the relative bearing of the two ships, the worst case being the head-on encounter. For this case the expected value for critical range is considerably larger than the "exact" value, and the confidence level for the best maneuver drops below 50 per cent for only 2 degree standard deviation in heading and bearing. The most probable best maneuvers do not usually differ from the best maneuvers based on the observed positions except for very large uncertainties in position.

Publications

Webster, W. C., "When is collision unavoidable?", Tenth Symposium on Naval Hydrodynamics.

Power from Salinity Gradients

Gerald L. Wick and John D. Isaacs

During the past year new insights were gained into the utilization of the energy existing at the interface of two solutions with different concentrations of salt. Progress was made toward understanding how to extract the energy using the vapor pressure difference between fresh water and brine. Some approaches to capturing the energy from pressure-retarded osmosis using semipermeable membranes have been eliminated. Also, data have been accumulated on salt deposits in the United States, with an eye toward their employment in salinity gradient power.

Initial interest in salinity gradient energy was directed toward the interface of freshwater rivers and ocean. There is, however, a much larger source of energy in the form of salt deposits. Salt domes located near or under the ocean, such as in the Gulf of Mexico, are particularly interesting. Calculations made during the year indicate there is more energy available from the salt in salt domes than there is in the oil which is extracted (Wick and Isaacs, in press). Salt domes comprise some of the largest oil fields in the United States. A typical salt dome can provide 10,000 megawatt years of energy when the salt is dissolved and interfaced with seawater. Brine disposal would not pose a serious problem if it can be amply diluted in the ocean or reinjected.

The vapor pressure difference between fresh water and brine can be as high as 70 mm of Hg or 0.1 atmosphere at moderately elevated temperatures. If the vapor above the two solutions is connected through a turbine, it is possible to extract energy from the system. Mass will transfer from the fresh water to the brine. During the year, we built a small test chamber maintained at a constant temperature, in order to evaluate the mass transfer rate. The chamber was in the shape of a flat cylinder with a copper sheet separating the two solutions. The copper was wetted by a rocking motion of the chamber. We tried several configurations with bare copper and with copper covered with cloth, both glass and cotton.

One of the biggest problems of this general approach is that the vapor transfers a great amount of heat as in the form of latent heat of vaporization. Unless this heat were transferred back to the fresh water side, the entire process would halt as the brine would heat up and the fresh water would cool. In our scheme, the copper sheet allows immediate transfer of the heat from the condensation side to the evaporation side.

Our tests of this chamber show that about 15 milligrams per second of vapor can be transferred between fresh water and saturated brine at 45°C. This corresponds to about 0.5 watts, or 25 watts per square meter of copper surface. This energy density is far greater than that achieved with other methods using membranes (Wick, in press). Furthermore, copper is cheaper and stabler than comparable areas of membranes. This energy density figure will actually be smaller when the power is extracted by a turbine which will have less than 100 per cent efficiency. Nonetheless, this technique (which can be considered as the reverse of vapor compression desalination) looks promising.

Osmotic pressure approaches eliminated

Our work with membranes for extracting salinity gradient energy by using the osmotic pressure appears less promising. We built a test chamber to measure the flow and the salt rejection properties of various semipermeable membranes and other porous materials. The highest flows were achieved with commercial membranes currently used in reverse osmosis desalination. These included cellulose acetate and poly(ether/amide). However, the flows were too low to consider these membranes for commercial energy production. The requirements of salinity gradient power are quantitatively different from those for desalination. Here we require large flows and only partial salt rejection; it is not necessary to have 99.9 per cent rejection. Membranes are probably far more susceptible to serious fouling (and clogging) than are the vapor transfer surfaces.

Further testing and research are continuing on all aspects of this program.

Publications

Wick, G.L., Power from salinity gradients, *Energy*, in press.

Wick, G.L., and J.D. Isaacs, *Science*, in press.

RAPID RESPONSE

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

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

Placement of Underwater Mass Concrete by the Tremie Method

Berkeley
R/NP-1Q

Ben C. Gerwick, Jr.

The purpose of this research was to develop the optimal concrete mix for underwater placement. The critical properties were workability and cohesiveness; that is, the lack of tendency to segregate and disperse into seawater.

Continuing beyond the extensive but now terminated research in the Netherlands, we conducted laboratory tests of various concrete mixes, admixtures, aggregates and cement types, to determine the optimal concrete mix for underwater placement. Of all the mixes investigated, the use of 15-20 per cent pozzolana replacement gave superior results. We correlated our laboratory findings with a Corps of Engineers project (Wolf Creek Dam, in Kentucky, for which I am a consultant), where this pozzolana is being used with excellent results.

Our detailed review of data from actual projects shows that the flow patterns are much more complex than those published in the literature. This was confirmed by small model (laboratory) tests. We found two flow patterns: one, a gradual flow under the surface; the second, an outflowing, like lava from a volcano. Preliminary indications are that this second mode can give almost equally satisfactory results. Large-scale tests on mixes and placing procedures are ready to be made; the large-scale box is ready.

We have recently identified heat of hydration temperature and volume changes as major factors in underwater tremie concrete placement. Mathematical analyses have been made and arrangements instituted to collect actual field data as well as similar data from the large-scale tests.

The State of Oregon and Federal Highway Administration will be cooperating in this extension of our original program, using data from the Columbia River Bridge Interstate I-205. We expect to complete the project and report by summer of 1978. If present trends continue, we will be able to offer a specification and a recommended practice that will significantly improve the present practice of underwater construction.

Longshore Sand Transport Studies

San Diego
R/NP-1O

Douglas L. Inman

We performed two longshore transport experiments during March 1977: the first on a day of large waves and pronounced longshore current; the second on a day of medium waves and weak or reversing current. In each case, beach sand tagged with fluorescent dye was injected in a line across the surf zone perpendicular to the shoreline. After the tracer sand had been in transit 1-2 hours, hand-held box samples and cores were obtained in a grid pattern north and south of the injection line. The dyed grains in each grab sample and in each cm of the core were counted, providing estimates of the depth of sand which was in motion and the average longshore transport rates of sand.

Cooperating Organizations

Jet Propulsion Laboratory, Pasadena, California
Naval Research Laboratory, Washington, D.C.
Shell Oil Company, Houston, Texas
U.S. Naval Post Graduate School, Monterey, California
U.S. Navy Fleet Numerical Weather Central, Monterey, California

Marine Resource Evaluation of Humboldt and Del Norte Counties, California: Preliminary Investigations

San Diego/Arcata
R/NP-1X

John D. Isaacs, Theodore H. Kerstetter, Steven L. Costa, and James W. Stork

This short-term, rapid-response project had the objective of gathering sufficient information to develop and submit for funding a program aimed at the identification of, research into, and ultimately the understanding sufficient to support the development and management of the marine resources of northern California. These primary goals have been realized, and a preliminary proposal has been drafted which will be submitted to Sea Grant for review.

Two of us (SC and JS) spent four weeks in the Eureka/Arcata area, contacting people from a host of organizations and agencies concerned with marine resource development. Most of this time was spent initiating discussions and soliciting ideas regarding the scope and thrust of the proposed project. Hindsight on our part vividly demonstrates that the preparation of such a proposal without these preliminary contacts would have been ill-conceived.

Numerous projects were identified which, if implemented and successful, would be valuable to the region both in terms of additional knowledge and actual applications in regard to the utilization of the marine resources of the region. Some of these are amenable to immediate implementation, while others are in need of varying degrees of further investigation. These projects are summarized in the Table. Selected examples are discussed below.

Projects for immediate attention

Certain projects were identified that are deserving of immediate attention and can be initiated and implemented with little or no preliminary development time. These include:

(1) Identification of fish school sonar traces using the free-fall camera recently developed at Scripps Institution of Oceanography. Briefly, the commercial fishermen in the region, and doubtless in many other areas, use sophisticated sonar equipment as an aid in locating fish schools. It is often the case, as we observed on a trip on one of these vessels, that the interpretation of these traces is ambiguous. Many people involved with the fisheries, including the working fishermen, were enthusiastic about using the camera in an extensive program to define and catalog the identity of the various sonar targets. This could best be done from the fishing vessels themselves. A set of parameters could be developed that correlated meter tracings, camera results, and species actually landed. A further suggestion involves placing a hydrophone and tape recorder in the camera housing to determine if the sounds produced by the fish might contribute to the identification.

(2) The possibility of the submarine extension of freshwater aquifers was brought to our attention. These may be manifested by submarine springs off the coast. It is noteworthy that one possible site of such activity is near the Eureka/Arcata urban area. The conductivity anomaly detector (CAD) recently developed at the Foundation for Ocean Research (FOR) is designed specifically for searching for such undersea features. This device, towed behind any vessel with an appropriate power source, remotely monitors large volumes of water and indicates any sources of anomalous conductivity, such as fresh water discharges. The determination of the existence of such springs is the first step in defining extended or new sources of water for the region.

(3) Annual expenditures involved in maintaining an adequate entrance to Humboldt Bay are ever increasing – as are those for maintenance of the interior channels. It may be, and most likely is, possible to use some of the new ideas about sand transport in tidal inlets to resolve this problem. Tidal augmentation schemes, utilizing the highly nonlinear relation between sand transport and channel discharge rates, are promising. Unfortunately, few data exist on the current structure in space and time in the channels of this bay. A minimum of these data would serve to evaluate the feasibility and preliminary design of such an installation.

RESOURCE DEVELOPMENT PROJECTS FOR THE NORTH COAST OF CALIFORNIA

Project	Priority	Status	Methods	Resource Category: Living: Natural	Resource Category: Living: Mariculture	Resource Category: Geological	Resource Category: Water	Resource Category: Energy	Resource Category: Transportation and Shipping	Resource Category: Recreation and Tourism
Fish identification (sonar trace/camera)	H	I	N	*						*?
Submarine springs (fresh water)	H	I	N				*	*		
Alternatives to dredging	H	S	N						*	*
Marine placers	B	S	N			*				
Harbors of Refuge	B	S	N						*	*
Trash fish	B	P	C	*						
Underutilized species	B	S/P	C/U/N	*	*?					
Pacific hake studies	B/H	S	C/U	*						
Littoral transport	B/H	S	N/C						*	*
Geothermal springs	B	S/I	N					*		
Internal bay currents and stratification	B	S	N/C	*	*				*	
Wave energy	L	P/S	N					*		
Mad River diversion	U	P	U	*	*			*		*
Artificial island (dredge spoils)	U	S	U	*	*					*

Priority: H = highest, B = intermediate, L = low, U = undetermined.

Status: I = immediate implementation, S = immediate study, P = preliminary study.

Methods: N = existing new methodology, C = conventional, U = undetermined.

Projects for future investigation

A host of other potential resources have been identified. Some of these require preliminary research in order to outline specific programs; others require more intensive investigation to define the feasibility of program implementation. (We are certain that many others have yet to be identified.) Resources in the former categories fall in all of the general categories. Examples within each category are given below:

(1) Biological resources — unutilized but potential marketability; the utilization of "trash" fish and fisheries wastes; further investigations into the future of a Pacific hake fishery in Eureka.

(2) Geological resources — submarine placers and their indication via monazites (no evidence for the existence of monazites in the adjacent land forms was unearthed during our visit, but their presence cannot yet be eliminated).

(3) Energy and water resources — the occurrence of submarine geothermal activity should be surveyed with the CAD (Cape Mendocino is a unique tectonic area); the feasibility of wave power installations should be investigated.

(4) Coastal features (harbors and bays) — the creation of harbors of refuge with tethered float breakwaters; the mapping of the interior currents of Humboldt Bay, possibly with the remote synoptic measurement techniques being developed at FOR, which would be of importance for many reasons, notably for any aquaculture activities in the Bay.

This list could be extended almost indefinitely, but the point to be made is that there are a great many projects, resources, and evaluation techniques to be considered.

Summary and recommendations

Our intent, as originally conceived, was threefold. First, we desired to initiate contacts and discussions, as well as solicit ideas and information, from as many individuals and organizations as possible. We also wanted to create an attitude of mutual cooperation with these contacts, which would be very

important in future work in the area. This, we feel, was an unqualified success! Second, we desired to demonstrate various pieces of hardware, in use, to a number of interested parties in the area. Because of the vagaries of procuring ship time, and unanticipated foul-ups with shipping the equipment, this phase of the project became one of "show and tell" sessions. However, we were successful in generating a great deal of interest and enthusiasm for each of the proposed techniques and methods. Finally, we desired to collect enough information to enable the preparation of a well-founded proposal to accomplish a marine resource evaluation – using as many new and unique procedures as possible. In this we were again quite successful. Much of the information collected, including library research results, unpublished data, and a small amount of field work, is being processed and organized and will be summarized in a supplementary report.

A preliminary proposal has been prepared for Sea Grant. This would be an intercampus effort between UC-San Diego and Humboldt State University. We strongly feel that the proposed program follows the objectives of Sea Grant and hope to be able to submit a formal proposal. We envision that the initial Sea Grant Program proposed will initiate much needed long-term research activities in the North Coast region which would eventually draw funding from a variety of sources.

Cooperating Organizations

California Department of Fish and Game, Sacramento, California
Eureka Fisheries, Eureka, California
Lazio Fish Company, Eureka, California
U.S. Army Corps of Engineers, San Francisco District
Winzler and Kelly, Eureka, California

Development of a California Coastal Wetlands Information Directory for Resources Management

Santa Cruz
R/NP-1W

Thomas Dickert and James Pepper

Individuals involved in public agencies with planning, management, and regulatory authority in the coastal zone frequently express the need for easy access to the published information on a given resource or resource complex. This project was designed to provide an initial component of an information directory to the literature on California's estuaries and coastal wetlands.

A series of eight wetland-specific bibliographies have been developed as prototype case studies. Preliminary literature classification and indexing systems have been developed and will be tested and modified through a user survey. A preliminary "natural systems" typology, classifying coastal wetlands according to important biological and physical characteristics, has also been developed; a similar review and modification by potential users will be conducted.

Meetings and conversations with local government agencies indicate significant interest in the development of a statewide information directory to assist public agencies in the development of the Local Coastal Plans mandated under the California Coastal Act. The results of this initial project will be incorporated in a major survey of potential users. The feasibility of establishing a Regional Coastal Information Center was also reviewed, and will form part of the user survey under the second phase work program.

Cooperating Organizations

California Department of Fish and Game, Sacramento, California
Local government agencies
Public and university libraries
State and regional coastal commissions

Pathogens of Marine Plant Aquaculture Systems

Lynda J. Goff

The overall objective of this project was to assess the impact of pathogens on marine plant aquaculture programs. The project involved a survey of 1) all literature on marine plant diseases and 2) of currently (and recently) operational plant aquaculture systems regarding disease problems.

The results of our surveys have been used to develop a technical report that will provide specific information on disease problems to future researchers in plant aquaculture. In this report, each identified marine plant pathogen is discussed and referenced. The disease-associated factors comprise (a) plant parasites, epiphytes, and endophytes; (b) fungi; (c) slime molds and *Labyrinthula*; (d) grazers; (e) copepods and nematods; (f) protozoa; (g) bacteria; (h) viruses; (i) pollution effects (including heavy metals, oil, detergents, biocides, thermal effluents, sewage and nuclear wastes); and (j) physico-chemical factors (i.e., salinity, turbidity, nutrients, light and wind). Specific diseases such as black rot, red rot, green rot and white rot are considered individually, as are disease problems in individual economically important benthic algal genera (i.e., *Porphyra, Macrocystis, Ascophyllum, Durvillea, Sargassum, Laminaria, Undaria, Chondrus, Gracilaria, Iridaea, Gelidium, Eucheuma,* and *Hypnea*). A list of key words has been developed for each reference, and all available references have been photocopied and are available through the Center for Coastal Marine Studies, University of California, Santa Cruz.

A literature retrieval program for the entire bibliography was developed using a PDP BASIC computer system. The program can be used to call out all references on any subject by key words, titles, dates, authors, etc. This entire program is available in magnetic tape form from the Center for Coastal Marine Studies, University of California, Santa Cruz, or UC Sea Grant. Programming and usage instructions are included in the Technical Report, which is available from the same two agencies.

In addition to this extensive literature review, over 1500 individuals active in private, government and academic research of plant aquaculture were contacted by letter, questionnaire and phone. Information regarding disease-related problems in currently operational aquaculture programs is included in the report.

It is hoped that the data base which has resulted from this project will serve as a starting point for future researchers in the field of marine plant aquaculture and pathology.

Publications

Goff, L.J., and J. Glasgow, 1977, Plant pathogens of aquaculture systems. Technical Report No. 7, Center for Coastal Marine Studies, University of California.

Cooperating Organizations

Over 100 state and federal agencies cooperated in this project by providing information. These contributors are listed in the Technical Report.

Bioeconomic Modeling of the Freshwater Prawn

Warren E. Johnston

The emergence of commercial production of freshwater prawns in Hawaii provides an opportunity for assessing the applicability of a modified computerized budget model, originally developed for lobster production. Important species and culture system differences are incorporated, but empirical application crucially depends on growth and mortality information.

A result of the project "Economics of Aquaculture", supported by the University's Sea Grant Program in FY 73-76, has been a computer simulation program for lobster aquaculture. It emphasized a variety of biological and physical as well as economic relationships, and was developed and used to assess the cost of lobster production, with state-of-the-art information provided by researchers at Bodega Bay, and elsewhere. The program was also designed to give guidance in indicating research areas with relative high potential pay-offs. However, a difficulty in applying it to lobster aquaculture was the inability to validate its economic results even though such validation was possible to some extent for biological performance measures.

The computer simulation program had always been intended to be non-specific, designed for potential adaptation also to other species and production systems. Shortly after its development, Schuur, Allen, and Botsford* used the simulation model to examine three alternative systems for the commercial production of *Homarus americanus*. Later, at the request of the National Sea Grant Program an effort to analyze the production of Japanese clams revealed some of the difficulties in program adaptation to other species and provided an opportunity for limited program development. The thrust of this current short-term project is to adapt and extend the simulation model, and test its applicability to cost assessment and research guidance problems for freshwater prawn (*Macrobrachium* spp.) culture.

Research on the freshwater prawn (*Macrobrachium*) is proceeding under Sea Grant program support at two main locations — Hawaii and South Carolina. In both of these, needs have been expressed for economic and systems analysis of the kind provided by the lobster model. Shang and Fujimura,** and Gibson and Wangt have reported activity for the Hawaii system of production, and the current Sea Grant program at the University of Hawaii proposes simulation model development that is philosophically very similar to the existent lobster model. Mutual interests coincided in fostering this activity to adapt the model to freshwater prawn culture: our interests and those of researchers in model development for their program assessment. The results of this project will be useful in fostering both sets of interests.

Hawaii system of production

Of the two main freshwater prawn production systems, the Hawaii system is the more complex since it involves repetitive harvest and restocking at intervals in a continuous production process throughout the year. Hawaii also has the largest research program on the freshwater prawn with a decade's experience in culture and commercial production, thus providing a locale which would reflect maturity in program (providing possible

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

**Shang, Yung C., and Takuji Fujimura, The production economics of freshwater prawn *(Macrobrachium Rosenbergii)* farming in Hawaii. Forthcoming in *Aquaculture.*

† Gibson, R. T., and Jaw-Kai Wnag, An analysis of alternative prawn production systems design in Hawaii. University of Hawaii Sea Grant Technical Report UN1H1-Sea Grant-TR-77-05, 1977.

insights into research priorities). And since commercial production already occurs in Hawaii, model validation sensitive to economic relationships and outcomes might be possible.

It was our hypothesis that the logical approach and to some extent the content of the lobster culture model could be modified to represent bioeconomic aspects associated with the emerging commercial production of freshwater prawns in the Hawaiian system of production. Initial activity on the project involved the very necessary efforts to become familiar with production systems and to collect reports and data which, it is hoped, would assist the development of the initial model. In this regard, the assistance of the State of Hawaii's Anuenue Fisheries Research Center (especially, T. Fujimura, Director) and the University of Hawaii Sea Grant Program (Dr. S. Malecha, Project Leader) were valuable in providing on-site inspection and support for the collection of information which largely serves as our knowledge base for modeling the freshwater prawn. However, despite commercial production, serious data deficiencies exist with respect to mortality and heterogeneous growth rates between males and females in the pond system of production. In our work, empirical application of the simulation model to freshwater prawn culture remains and is, in part, contingent upon the outcome of our work to obtain useful estimates for growth and mortality rates from periodic population and harvest sample data for only two production ponds.

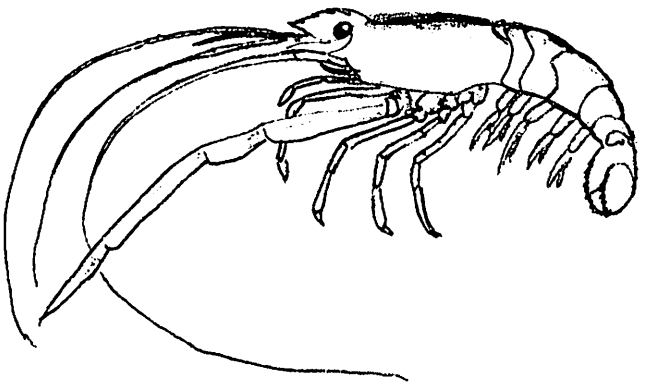
Study initiated under this project is proceeding through the next year with the objective of making empirical the simulation model for freshwater prawn culture. The previous simulation model has been simplified to FORTRAN to yield greater flexibility in its use by a growing number of users and in facilitating the modifications necessary in changing species focus. The model has been modified to accommodate important aspects such as multiple harvesting and the restocking of a variable population under the system of year-round production. And potentials for assessing multiple-stocking strategies are incorporated to reflect that option, as hatchery capabilities expand from the current seasonal to the year-round supply of post-larval juveniles to the emerging industry. These important aspects and alternatives will be quantitatively evaluated when adequate parameter estimates are determined during the continuance of this project.

Publications

Allen, P.G., Aquaculture simulation package: Lobster production (Version: NEWLOB2), Department of Agricultural Economics, University of California, Davis, California, 1977.

Cooperating Organizations

State of Hawaii Fisheries Research Center, Anuenue, Hawaii, University of Hawaii Sea Grant Program, Honolulu, Hawaii



Astaxanthin from Yeast

Davis
R/R-11

M.J. Lewis

The bright, orange-red carotenoid pigment astaxanthin is a necessary component in diets of various marine animals if their native color is to be maintained, yet sources are limited. We have recently shown that the pink, astaxanthin-containing yeast *Phaffia rhodozyma*, if fed to trout, causes them to become a desirable bright pink color. In addition we have scaled-up fermentations to 60 liter size to confirm that this yeast can be grown commercially and, by optimizing conditions of growth, we have increased the pigment yield nearly tenfold. Problems remain, but a cheap and effective source of astaxanthin could be on the horizon.

Red salmon or red lobster or crabs are more attractive than those pale in color. Thus, an important factor affecting consumer acceptance of pen-reared salmonids or crustaceans is the color of their flesh or carapace. Astaxanthin is the carotenoid pigment responsible for the red color of these animals. Unless this natural coloring agent is supplied in their diet, these animals will not develop their native red coloration since their bodies are unable to make carotenoid pigments. A particular problem when raising salmonids or crustaceans intensively in fish farms is to find an effective but cheap source of dietary astaxanthin.

The yeast *Phaffia rhodozyma* has the special property of making large amounts of the carotenoid pigment astaxanthin. Indeed, it contains 10 to 30 times more astaxanthin than such materials as waste shrimp which are commonly used sources of dietary pigments for fish feeding. The amount and quality of pigments in the yeast is dependent upon the yeast's conditions of culture. For example, if the yeast is grown with a limiting air supply or a high sugar concentration, it produces very little astaxanthin. Changes in temperature, on the other hand, influence the growth rate of *P. rhodozyma* but only slightly alter its pigment composition. A rich medium with a certain acidity (pH 4.5) supports best pigmentation. Our work on the optimization of these conditions of growth of the yeast has allowed us to produce large quantities of yeast containing high concentrations of pigment for fish feeding trials.

Need for processing the yeast

Rainbow trout fed a diet containing 15 per cent (w/w) *P. rhodozyma* rapidly absorbed astaxanthin, and the fish flesh became highly pigmented in only 37 days. The carotenoid which accumulated in the flesh of these animals was confirmed to be yeast astaxanthin. Thus, there is no doubt that the yeast is an effective pigment source for fish. But this yeast has to be treated in a special way. We found that the rainbow trout did not have the ability to digest and absorb pigment from intact yeast cells, but rapidly absorbed carotenoid pigments from processed *P. rhodozyma*. Our method of processing the yeast is expensive and therefore not yet commercially attractive. We see no reason, however, why we should not improve on our present technology. This has led us to an investigation of the thick, protective yeast cell wall. We have removed the wall of this yeast, using enzymes from another micro-organism. This crucial step allows us to find the location of astaxanthin inside the yeast cell and to find out how it is attached. This is an important preliminary for freeing the astaxanthin.

Fish fed a commercial fish-coloring diet (Ewos) did not grow as fast as those fed the diet containing the red yeast, but colored almost as readily.

In summary, we have determined the yeast to be a valuable source of astaxanthin which can be rapidly absorbed into the flesh of rainbow trout that have fed on this yeast. We have increased the pigment yield in the red yeast to nearly 0.1 per cent (1 mg/g) of the yeast dry weight and have demonstrated its nutritional value for cultivated rainbow trout.

Publications

Johnson, E.A., D.E. Conklin, and M.J. Lewis, The yeast *Phaffia rhodozyma* as a dietary pigment source for salmonids and crustaceans, *J. Fish. Res. Board Can.*, Vol. 34, in press.

Cooperating Organizations

Bodega Marine Laboratory, Bodega Bay, California
California Department of Fish and Game, Sacramento, California
Hoffman-La Roche, Inc., Nutley, New Jersey
Sigma XI, New Haven, Connecticut
Union Carbide Corporation, Tarrytown, New York

Analysis of the Santa Barbara Inshore Partyboat Fishery and Aspects of the Life History of the Olive Rockfish, *Sebastes Serranoides*

Alfred W. Ebeling

There is increasing pressure by various interest groups on the marine resources of the Southern California Bight. In Santa Barbara, the sport and commercial fishing industry, oil companies, and numerous other business and recreational interests vie for both space and marine organisms.

It is the intent of this project to analyze the inshore sport fishing partyboat industry. Emphasis will be placed on analyzing which fish are most important to the industry and which areas are fished most heavily. In addition, work will continue on the life history of the olive rockfish, *Sebastes serranoides*, an important sport fish.

Partyboat sportfishing in California is a multimillion dollar industry. Over 6500 passengers per year are carried by the coastal partyboat from Santa Barbara. This represents revenues of perhaps as much as $100,000, primarily from sales of tickets and equipment rental, etc.

Competing interest groups

There is increasing competition by recreational and commercial groups for the use of a limited number of coastal marine areas. Examples of this are: (1) competition for a specific resource, such as fishes, between commercial, hook-and-line and spear fishermen; and (2) competition for habitats, as between fishermen, oil interests and various conservation groups. In the future this conflict will certainly continue, if not intensify. Decisions should probably be made on the allocation of various reefs, kelp beds, etc. for optimal return, but first of all it would be beneficial for the competing interest groups to know to what extent, and by whom, the various marine habitats are being used.

With regard to the partyboat sportfishery, no objective documented analyses have been made as to what specific reefs are fished, how much time is spent on each reef, what fish are taken, their size frequency and the catch per unit effort. Moreover, for many of these fish, little is known about their growth rates or at what size they mature.

Our project has two goals: (1) to analyze the coastal partyboat sportfishery in Santa Barbara and (2) to detail the life history of one of the most important sport fish in central and southern California, the olive rockfish, *Sebastes serranoides.*

Analysis of the Santa Barbara inshore partyboat fishery

Some of the most significant aspects of the fishery include catch composition, and the abundance, size frequency and state of maturity of the species taken. We sample aboard the vessel about once per week (15–20 per cent of its total trips) to gather data on these factors. On board, every fish caught is measured and identified. Over the past year, we have measured 7993 individuals, representing 60 species. Rockfish, genus *Sebastes*, made up about 75 per cent of the total catch and the species most often taken (24.3 per cent of the total) was the olive rockfish, *Sebastes serranoides.*

We are conducting a study on the age, growth and maturity of each important species taken in the local sportfishery. Preliminary analysis indicates that at least 50 per cent of the rockfish taken are immature. As rockfish make up a large fraction of the total catch, this would indicate that much of the inshore sportfishery is based on immature fish. This is unusual, as immature fish are not usually important to a fishery. Fishermen tend to avoid populations of small, immature fish, if larger ones are available. Government regulations also limit the number of these fish taken, via minimum size limits, gear regulations, etc.

For the past two and a half years, we have conducted interviews about three times a week with the vessels' operators who are asked where and for how long the vessels

fished the previous days. While sampling aboard the vessel, we measured the time fished at various reefs during the trip and compared these measurements with the estimates by the operator. Based on these tests, the latter were found accurate to within about 15 per cent. Our data indicate that the oil platforms are the single most heavily utilized "reefs."

Our study will include an analysis of the catch-per-unit effort over the various reefs for a two-year period and changes in catch composition with season, plus a demographic analysis of the partyboat's passengers.

Aspects of the life history of the olive rockfish, *Sebastes serranoides* — growth, maturation and reproduction

Initial studies were carried out on fish from shallow water (less than 30 m) from Avila and Santa Barbara. It was apparent that Avila fish grew faster than did Santa Barbara ones. We hypothesized that the colder Avila water temperatures were at least partially responsible. If this were true, it would be expected that fish in the colder water Santa Rosa-San Miguel Island area would grow faster than fish from the warmer Santa Cruz Island.

For the island comparisons, we collected fish from Talcott Shoals on the west end of Santa Rosa Island and from the north side of Santa Cruz Island (between Fry's Harbor and Pelican Anchorage). We found that fish from Avila and Talcott Shoals grow at similar rates and that this rate is higher than that of fish from Santa Cruz Island and Santa Barbara.

We also raised olive rockfish in temperature regimes similar to those of Santa Barbara and Avila, and captured 22 fish from the shallow Horseshoe Reef off Summerland; 11 were placed in each of two tanks. The fish were measured (total length) and tagged by clipping a dorsal spine. The Santa Barbara tank contained water pumped directly from Goleta Bay, while water was run through a cooler to a second tank and adjusted monthly to Avila surface temperatures (as reported from Port San Luis). The fish were fed chopped anchovies (twice per week) to satiation, and were measured every four months. The study began in December 1973 and terminated in August 1974, when a shutdown of the seawater system killed the Santa Barbara fish.

Fish in the colder tank grew at a faster rate than did those in the warmer tank. Mean increase in length was 6.09 cm in the cold tank and 2.54 cm in the warm one. Differences were significant at $P < 0.001$.

This section will also include such topics as size and age at maturity, fecundity and spawning season.

Parasites. We are interested in the parasite-mix of *S. serranoides.* Our intention is to identify: (1) what parasites infect the species, (2) what trends (if any) exist in the mix, associated with season and host size, (3) differences between parasite-mixes of fish in different geographical locations and (4) the spatial relationships between various parasite species within or on the host.

The bulk of the study was carried out on fish taken from the Avila area. The reefs there support very large numbers of olive rockfish which have a wider size range than populations found closer to Santa Barbara.

More than 35 species of parasites infect olive rockfish. Of these, about 30 had not been previously reported from this host and four species were new to science. We (with Mike Moser) have described these in publications. We are also redescribing and synonymizing three species of the digene genus *Deretrema,* a form found in rockfish gall bladders.

There is good evidence that some parasites infect *S. serranoides* seasonally. These are the stomach and intestinal nematode *Thynnascaris aduncum* and the intestinal digenes *Opechona sebastodis* and *Opecoelus* sp. All seem to be present from late spring to early fall and absent during the rest of the year.

Host size seems to be correlated with parasite-mix. A number of parasites, notably the protozoan *Henneguya sebasta, T. aduncum,* and *O. sebastodis* are found primarily on mature fish, while the copepod *Clavella parva* is found only on small (less than 20 cm standard length) individuals.

A few geographical differences in parasite infections have been found. For instance, the Pt. Conception region may be the northern limit of a mouth copepod *Caligus* sp. No members of this species have been found north of the Point.

Movement. Rockfish are important to the California sport and commercial fishing industry (about 80 and 7 per cent of the total

catch respectively). However, little is known about their movements (if any).

Olive rockfish first appear as juveniles in April through June in kelp canopies and over rocky reefs. There is some evidence that, at least off Catalina, late juveniles move into deeper water as they mature (E. Hobson, personal communication). We initially believed this phenomenon occurred off Santa Barbara, as we could not find mature fish in shallow water. It now appears that the reefs we first sampled were heavily fished by sport fishermen, and that most of the larger fish had been taken. We have now found some adult olive rockfish in shallow water, in unfished areas.

Over a three-year period, we tagged 1847 olive rockfish over a number of reefs, primarily in southern California. A total of 189 tags have been returned thus far. Only three fish showed substantial movement, having moved between oil platforms off Summerland—a distance of about 2 miles.

We decided to see if parasites could be used as biological tags to supplement the information we were receiving from the tagging program. We hypothesized that olive rockfish on inshore reefs did not travel great distances and that different reefs might harbor fish with different parasites or different infection rates.

Thus, we collected fish from a number of adjacent reefs in the Santa Barbara area and examined their parasite mixes. Generally, we found little difference in infection rates. However, there was a significant difference between fish on Naples Reef and those near the Ellwood Pier. About 30 per cent of the fish taken at Naples Reef carry the monogene *Microcotyle sebastis* on their gills; none is found on those from Ellwood Pier. As Ellwood is quite close to Naples Reef, this suggested that movement of *S. serranoides*, at least in that area, was quite restricted.

Food habits. The food habits of juvenile and subadult olive rockfish in the Santa Barbara area have been described by Love and Ebeling (in press). We found that these fish fed primarily on midwater nekton and plankton. We have now conducted a more extensive survey at Avila. Over 600 fish from a two-year period were sampled. The collection included fish from throughout the species' size range. All food items were classified to lowest possible taxa, counted, weighed and their volumes measured. The analyses will include comparisons of food item weight, number and frequency of occurrence with season and fish length.

Publications

Love, M. S., and A. W. Ebeling, Food and habitat of three "switch-feeding" fishes in the kelp forests of Santa Barbara, California. *Fishery Bull. U.S.*, in press.

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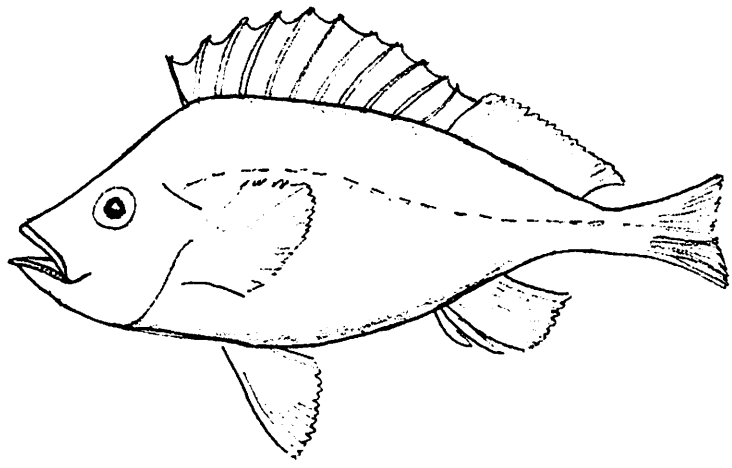
Moser, M., M. S. Love, and L. Jensen, Myxosporida (Protozoa) in California rockfish, *Sebastes* spp., *ibid.*, 62(5), 690-692 (1976).

Cooperating Organizations

California Department of Fish and Game, Sacramento, California

Sealanding Sportfishing, Inc., Santa Barbara, California



Investigation of Data for an Economic Study of the U.S. Pacific Albacore Jig Boat Fishery

San Diego
R/NP-1S

Suzanne Holt

The activities of U.S. fishing fleets have long been a subject of study by biologists intent on determining the extent and behavior of fish populations and the impact of fishing on these populations. However, much less is known about socioeconomic factors that affect the behavior and decision-making of fishers. Such is the case for the jig boats that fish for albacore tuna on the West Coast.

Although the U.S. Pacific albacore jig boat fleet has a well-developed logbook data system used for determining the availability of albacore and the extent of fleet activity, there is little information on the costs of fleet activity or the extent to which jig boats participate in other fisheries. Such information is crucial to understanding the impacts of fishing regulations or economic fluctuations on fleet size and activity, fisher income and landings rates. For example, will a potential future quota on U.S. annual albacore landings generate additional unemployment and/or activity in the salmon and crab fisheries? What effect would widespread unemployment in coastal areas have on the size of fleets and landings and the replenishability of the fish populations?

Development of field survey

It has been the purpose of this study to determine the size of the albacore fleet in Washington, Oregon, and California, and to design a field survey to elicit information on cost categories in albacore fishing and participation rates in various fisheries. In addition, the field survey has been designed to gather data on the extent to which persons engage in commercial fishing because of lack of other income-earning opportunities or because of nonmonetary enjoyment factors associated with fishing. Several experts in the field of questionnaire design as well as fishermen's associations and Marine Advisors made valuable contributions to the survey format.

Using fleet size data from the commercial fishing licenses of the three states, a random sample was drawn of 80 fishers to be contacted for intensive field survey. This sample was stratified according to vessel length, geographical distribution, and success rates in albacore fishing.

Existing raw data on the Oregon commercial fleet were analyzed and will be used as a check against data gathered with the questionnaire resulting from this study.

In August and September, the survey design was tested on a few commercial fishers in San Diego and Moss Landing, with highly successful results. From this outcome, it was concluded that the survey, properly designed and administered, would generate high response rates.

The questionnaire developed on the basis of this study will be administered to a sample of albacore fishermen in the following year as part of a project entitled "An economic study of the U.S. Pacific albacore jig boat fishery." Aggregation and analysis of the resulting data will prove to be valuable information for the albacore fleet itself, making it easier for individual fishers to gauge their economic position relative to that of other boat operators. In particular, vessel owners will be able to evaluate their operation, in terms of cost and catch success, against the average performance level of vessels of equivalent size. Such increased information will allow the fleet to operate more efficiently.

Cooperating Organizations

American Fishermen's Research Foundation, San Diego, California

California Department of Fish and Game, Long Beach, California

Center for the Quality of Working Life, UC-Los Angeles, Los Angeles, California

Marine Advisory Extension Agents of California, Oregon and Washington

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

Oregon Department of Fish and Game, Portland, Oregon

San Diego State University, Social Science Research Lab., San Diego, California

Washington Department of Fisheries, Seattle, Washington

Western Fishboat Owners' Association, San Diego, California

Development of Trapping Methods for Migratory Salmonid Smolts in Hatcheries

Theodore H. Kerstetter

Anadromous fish hatcheries typically raise juvenile salmon and steelhead trout to a stage in their life cycle when release into a river would be rapidly followed by downstream migration. Release at that time minimizes the period that young fish must spend in fresh water and also helps to ensure their physiological readiness to adapt to salt water when they reach the sea. The problem from the fish culturist's point of view is deciding on the optimum release time for the different hatchery stocks.

Steelhead, the seagoing rainbow trout of the Pacific slope, typically spend from one to three years in their natal stream before moving down river to the ocean. The seaward migration occurs in the spring and is preceded or accompanied by a series of physiological and behavioral changes, collectively called smolting, which prepare the young trout for life in the ocean. Among the changes associated with smolting are a change to a silvery color, a decrease in body fat, downstream migratory behavior, and a marked increase in the levels of an enzyme, sodium + potassium-activated ATPase, which is necessary for life in highly saline water and which can be measured in gill tissue. Smolts which do not enter salt water revert to the freshwater, or parr condition within a few weeks. Hatchery operators try to release young steelhead at the peak of the smolting season, but since all fish of a given age do not become smolts simultaneously, it is inevitable that some are released too soon and some too late. The result can be heavy mortality and/or overloading of the river with young, non-migrating steelhead.

Two-stage gate design

The purpose of this project was to develop a method of selecting smolts in hatcheries as soon as migratory behavior appears. Although we worked with steelhead trout, the methods that were developed are equally applicable to most salmon species. We sought to take advantage of the smolt's urge to travel down a current by installing gates through (or over) which an accelerated current was made to pass. A variety of configurations were tested in two hatcheries, Trinity at Lewiston, California, and Mad River Hatchery near Arcata. In both hatcheries yearling steelhead were kept in elongated ponds, or raceways, through which a slow current of water moved continuously. The gates we tested forced the current through small openings at the downstream end of the raceways; enclosures below the gates held the fish which had moved through. The most successful gate design (Fig. 1) was operated at Mad River Hatchery and consisted of two stages: a wooden dam in series with a pipe gate. Fish moving into the holding area first had to pass over the dam and then had to swim through a 3-foot long section of 4-inch pvc pipe which formed the only passage through a second dam (see Fig. 1). A 4-inch hydraulic head at the second dam, or pipe gate, produced a velocity through the pipe in excess of 3 feet per second.

In addition to recording the numbers of fish moving through the gates each week, we also measured both the condition coefficient (100 x grams of body weight/length^3 in cm)

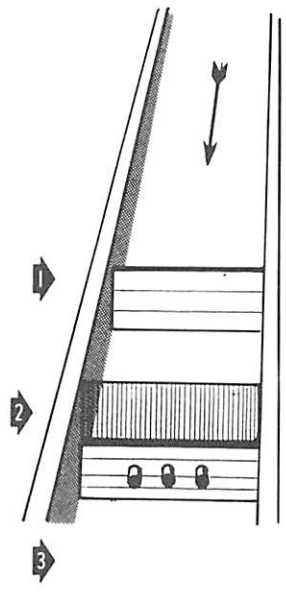


Fig. 1. Smolt trapping system at Mad River Hatchery. Long arrow indicates direction of current flow. 1. Solid dam; 2. pipe gate; 3. holding area

and the levels of ATPase in gill tissue of both "migratory" and non-moving fish each week. The purpose of the latter two measurements was to ascertain how closely correlated migratory behavior was to loss of body fat and increased levels of ATPase in gills. Good correlation between downstream movement and either or both of the other two smolt characteristics would be evidence that the gates were indeed selecting for migratory behavior.

At Mad River Hatchery we worked with a population of 2100 ± 100 fish. The rise in gill ATPase started well before migration (Fig. 2b), and in fact, peak values for the enzyme were noted about one month before appreciable migratory movement occurred. Furthermore, there was no correlation between ATPase levels of migrating and non-migrating steelhead. But in 7 of the 11 weeks for which condition coefficient was measured, fish which had moved through the gates had a significantly lower mean value than non-moving fish. For the entire 11-week period the difference between the two groups (migratory and non-migratory) was highly

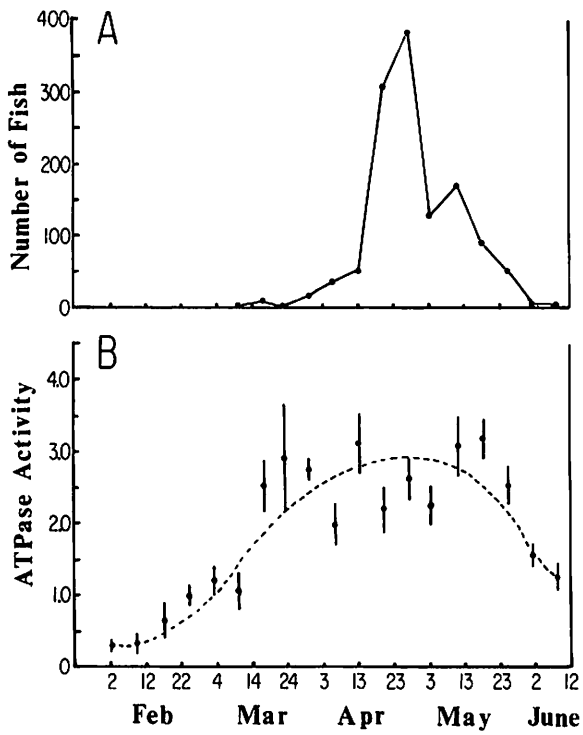


Fig.2. a. Weekly totals of fish moving through gates at Mad River Hatchery. b. Seasonal pattern of Na, K-ATPase activity in Mad River yearling steelhead. Vertical bars are standard errors. ATPase activity is in μmoles of phosphate released per hr per mg protein

significant. The pattern of movement through the gates (Fig. 2a) was also highly suggestive that we were indeed selecting for migratory behavior. Appreciable movement did not begin until early April; relatively large numbers moved from mid April to mid May, and by the end of May movement had essentially stopped with 38 per cent of the original population still remaining in the raceway.

At Trinity Hatchery two single-stage gates were installed side by side in one raceway in late January. Each consisted initially of a wooden dam with a small opening, 6 in x 6 in in one dam, and 20 in x 6 in in the other. Condition coefficient and gill ATPase were measured by personnel of the California Department of Water Resources Region 2 office in Red Bluff. Movement through both gates was initially so high that we felt random movement was responsible, and we installed pipe gates similar to the one described for Mad River Hatchery, but without a solid dam as a first stage. About 10 per cent of the raceway population moved through the two gates the first week, but numbers rapidly tapered off thereafter. Warming hatchery water necessitated the release of all steelhead in the raceway the first week in April, terminating this phase of our work. But statistical analysis of the pooled condition coefficients for both migratory and non-migratory steelhead showed a significant difference between the two groups. Thus the simpler gates used in the Trinity Hatchery, while probably not as effective as the Mad River gate system, nevertheless showed some selection for migratory behavior.

We do not view the failure to achieve 100 per cent movement at Mad River as discouraging to the potential of the smolt trapping concept. First, it is possible that not all yearling steelhead in a hatchery population develop a downstream migratory urge. (Wild steelhead usually migrate in their second or even third year of life.) And second, it is likely that modification of the gate system as described would allow a higher percentage of fish to move, while still discouraging random movement.

Cooperative Organizations

California Department of Fish and Game, Sacramento, California

California Department of Water Resources, Sacramento, California

An Ethnography of the San Pedro Wetfish Fleet

Carlos G. Velez-I.

The purpose of this project was to gain insight into the world of the fisherman, both its technological and social aspects.

On July 1, 1977 a small award and traineeship were granted to the Chicano Studies Center to conduct an ethnographic study of San Pedro's local wetfish fleet. The activities of the trainee and the project leader, therefore, are reported for only two months: August–September.

For both the trainee, David Morrill, and myself, familiarity with the technology of the local fleet was one of the initial goals. However, since David and I were in fact "beach" persons and not fishermen by interest, avocation, or profession, it was imperative that we literally begin "to get our feet wet" in a systematic manner. We therefore enrolled in a commercial fishing class which was sponsored by one of the local occupation centers. Thus, for eight weeks we have been engaged in learning what I would consider a "cultural system" as unfamiliar as that of a Micronesian atoll.

Attendance at classes

The classes were held in the local fishermen's cooperative building, and for six to eight hours at a stretch we were taught basic elements of the fisherman's life. I must point out however that the classes also served a different function, which we had anticipated. Like many occupations, fishing is bound by traditions regarding its methods and technology, but also, in this case, by ethnicity. These classes served not only as an "introduction" to groups in which a highly specialized way of making a living was important, but also as a means of "cracking" group loyalties and ethnic perceptions. Acceptance for the trainee and myself as observers and participants would have been impossible without a rudimentary knowledge of not only the technology of the occupation but, also and more importantly, its cultural aspects.

From learning to splice ropes to mending nets, from acquiring knowledge of dead reckoning to the internalization of cultural beliefs regarding do's and don'ts of behavior, from acknowledging the exhortations regarding the "value" of hard work to its implementation in actual practice aboard aging vessels, from participating in "bull" sessions about the risks that valiant men take in this occupation to inhaling the foul, oil-soaked odors while bailing a hatchful of illegally caught mackerel, David and I were very soon initiated into the pragmatic, backbreaking work of the sea. Soon we adjusted to the necessary intimate social relationships — the "culture" of multi-ethnic fishermen.

We have achieved our initial research goals of searching out, and negotiating with, vessel owners for the purpose of our investigations, and the trainee and myself are presently engaged in the collection of gear inventories aboard two vessels. Two other vessels have been selected, but interest by the skippers remains to be kindled. Largely because of the distrust of "outsiders," intimate social relations with crew members have yet to be established. However, it is expected these will be generated as time goes on. A key person in the various spheres of exchange that make up the economic system in this local industry has been most helpful in providing us with insights into the way in which trading and price agreements are of a very personal and non-standard nature. We cannot, however, afford to press the collection of data with undue haste without jeopardizing carefully built-up sources of information.

In addition, the trainee and myself will continue the careful observation of shipboard life of the local boats during the actual fishing operations. While both of us have made various trips and have served not only as "guests" but also as common hands, we have quite a chore in store. This is the balancing of data-gathering responsibilities with demanding occupational requests from skippers and crew, which are sometimes mutually exclusive.

Cooperating Organizations

Harbor Occupational Center, San Pedro, California

San Pedro Fishermen's Cooperative, San Pedro, California

Yugoslav–American Club, San Pedro, California

Food Conversion Efficiency of Early Post-Larval Dungeness Crabs

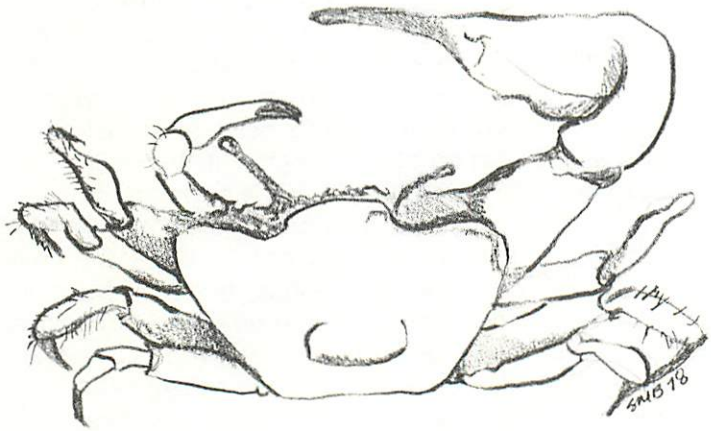
Earl Ebert

A trainee at the Granite Canyon Marine Culture Laboratory fed early post-larval Dungeness crabs *(Cancer magister)*, four different diets: (1) live adult brine shrimp *(Artemia salina)*, (2) frozen squid *(Loligo opalescens)*, (3) fresh squid *(L. opalescens)*, and (4) skate (Family Rajidae). The best food conversion efficiency of ingestion (dry weight of food: dry weight of crab) was produced by the *Artemia* diet (12.52:1), followed by frozen squid (17.51:1), and fresh squid (41.32:1) diets. Analysis of food conversion for skate-fed crabs was incomplete due to poor growth and low survival (13 per cent). Survival was relatively high on all other diets (80-93 per cent).

Growth and intermolt periods were essentially the same for all diet-fed crabs, except skate. Ingestion rates were significantly different for each diet.

In conducting dry weight measurements, water contents of different foods vary considerably. Live crab weight through instar V averaged 73.3 per cent water during the intermolt condition.

Overall assessment of a production feed must consider food conversion efficiency, normalized biomass increase, and diet costs. Since growth rates of laboratory-reared Dungeness crabs were relatively low when compared with natural populations, mariculture of early juveniles, under present experimental conditions, does not appear very attractive.



Thermophilic Microorganisms Isolated from Undersea Hot Springs, Electric Power Plant Condensers, and Ships' Heat Exchangers

San Diego
R/NP-1P

Francisco V. Vidal, Victor M. V. Vidal, and John D. Isaacs

This research has established that submarine hot springs and the surfaces of heat exchangers of seawater-cooled power plants are populated by thermophilic microorganisms. Through elucidation of their metabolic processes, it may be possible to devise an environmentally acceptable and specific method to control their growth and accumulation in these heat exchangers, where they seriously interfere with heat exchange efficiency.

During the past 12 months we have attempted to determine whether thermophilic microorganisms generally exist in the sea – where we have found them populating submarine hot springs – and whether they grow in the heat exchangers of seawater-cooled power plant condensers where they might be responsible for the deterioration of heat exchange efficiency. In this context, our research efforts were directed towards the development of an efficient and environmentally appropriate system to control the growth and accumulation of thermophilic microorganisms in such heat exchangers. At the same time, we planned to investigate the chemistry of the Punta Banda submarine hot spring waters as well as the mineralization processes that occur when submarine hot spring waters meet cold seawater. We proposed to design, develop and construct an instrument package that would allow us to study thermophilic bacterial growth rates and heavy metal uptake *in situ*, in the submarine geothermal area off Punta Banda, Baja California, Norte Mexico.

Considerable advances have been achieved in these investigations. We have conclusively determined that thermophilic microbes populate both submarine hot springs and power plant condensers. In these latter structures, thermophilic microorganisms are responsible for the deterioration of heat exchange efficiency. This is the first time that thermophilic microorganisms have been isolated from these environments and identified as one of the principal factors in the deterioration of heat exchange efficiency in seawater-cooled power plant condensers.

The equipment to study these microbial populations in the laboratory and in the field has been constructed. An appropriate culture media has been formulated to grow the organisms under controlled conditions.

Optimum requirements of organisms

The optimum environmental growth parameters, temperature and salinity, have been studied. The results show that the isolated strains have an optimum temperature for growth between 57°C and 65°C, and that they resist temperatures as high as 82°C. Their optimum salinity for growth is 0.25 moles NaCl. They prefer low NaCl concentrations and cannot grow in concentrations in excess of 1 M NaCl (i.e., 2.2 times the salinity of seawater).

The specific ionic requirements of the microorganisms have been studied. It has been determined that all strains under culture do not have specific gross requirements for Na^+, K^+, Mg^{2+}, Ca^{2+}, and are similar to estuarine organisms in this respect.

We have not isolated strict anaerobes from the Punta Banda submarine hot springs. All of the strains isolated from these springs are facultative anaerobes. Those isolated from the Encina power plant include both types.

Analysis of organisms

The taxonomic analysis of all strains is under way, and approximately 80 per cent of all necessary tests have been performed. However, not until they are all completed will we be able to identify the organisms. A detailed analysis of their fatty acids content has been made, and the data are being reviewed. Since 90 per cent or more of the lipids of bacteria are found in their cell wall membranes, we believe that a detailed analysis of the lipids of our strains will enable us to propose a method by which we can eliminate the growth of these thermophiles in power plant condensers and seawater heat exchangers in general.

The instruments for the collection of thermophilic microorganisms at the submarine hot springs for quantitative heavy metal analysis will be installed soon. This analysis can tell us whether the organisms take up toxic heavy metals under natural conditions. Subsequently we will perform toxicity tests under laboratory conditions to determine the tolerance levels of these bacteria before toxicity is observed.

Chemical characteristics of submarine hot spring waters

We have conducted the *in situ* observations of submarine hydrothermal activity in Punta Banda, Baja California, Mexico, approximately 400 meters off the coast and at a depth of 30 meters. The hydrothermal activity occurs within the Agua Blanca fault, a major transverse structure of Northern Baja California. Hot spring water samples have been collected. and analyzed. Marked differences exist between the submarine hot spring water, local land hot spring waters, ground water, and local seawater. SiO_2, HCO_3, Ca, K, Li, B, Ba, Rb, Fe, Mn, As and Zn are enriched in the submarine hot spring water, while Cl, Na, SO_4, Mg, Cu, Ni, Cd, Cr and perhaps Pb are depleted vs. average and local seawater values. Very high temperatures, at the hydrothermal vents, have been recorded (102°C at 4 atm pressure). Visible gaseous emanations rich in methane and nitrogen coexist with the hydrothermal solutions.

Metalliferous deposits, pyrite, have been encountered with high concentrations of Fe, S, Si, Al, Mn, Ca and the volatile elements As, Hg, Sb, and Tl. X-ray dispersive spectrometry (1500 ppm detection limit), X-ray diffraction (XRD) and scanning electron microscopy of the isolated metalliferous precipitates indicate that the principal products of precipitation are pyrite and gypsum, accompanied by minor amounts of amorphous material containing Si and Al. Chemical analyses and XRD of the reference-control rocks of the locality (volcanics) vs. the hydrothermally altered rocks indicate that high temperature and pressure water-rock interactions can in part explain the chemical characteristics of the submarine hydrothermal waters. Tritium dating of the hydrothermal solutions gives them an undetermined old age. Their long residence time, the occurrence of an extensive marine sedimentary formation, their association with methane and their similarities with connate waters of oil and gas fields suggest that another component of their genesis could be in cation-exchange reactions within deeply buried sediments of marine origin.

The approximate volume discharge of the hydrothermal system has been measured (330,000 m^3/yr) and the overall convective heat flux over the mapped submarine hydrothermal area has been calculated. This value exceeds by a factor of 10^5 the reported average conductive flux through the sea floor. Our data and observations indicate that metal-rich marine sediments and marine ore forming processes are a concurrent reality and are being formed today in submarine areas of high convective heat flow where hydrothermal activity is the precursor for their occurrence. At the same time, the results of our investigations have demonstrated that submarine hydrothermal activity and submarine hot springs exist in the ocean in regions characterized by relative quiescence and that tectonically "active" ridge environments are not an exclusive prerequisite for their existence.

Publications

Vidal, V. M. V., F. V. Vidal, J. D. Isaacs, and D. Young, Coastal submarine hydrothermal activity off northern Baja California. *J. Geophys. Res.*, in press.

Cooperating Organizations

Consejo Nacional de Ciencia y Tecnologia de Mexico, Mexico, D. F.

Escuela Superior de Ciencias Marinas, Universidad Autonoma de Baja California Norte, Ensenada, Baja California Norte, Mexico

Foundation for Ocean Research, San Diego, California

San Diego Gas and Electric Company, San Diego, California

Southern California Coastal Water Research Project, El Segundo, California

United States Geological Survey, Menlo Park, California

University of California, School of Medicine, San Diego, California

University of California, Tritium Laboratory, La Jolla, California

University of California, Veterans Administration Hospital, La Jolla, California

PROGRAM SUMMARY

Project Title/Project Leader	FY75	FY76	FY77
PROGRAM MANAGEMENT			
Management and Program Development (Sullivan)	O	O	O
EDUCATION/TRAINING			
Sea Grant Trainees (Sullivan)	O	O	O
Undergraduate Training in Marine Technology (Flittner)	C	–	–
Model Course in Marine Planning (Burton)	–	N/C	–
ADVISORY			
Ocean Education for the Public (Wilkie)	O	O	O
Marine Advisory Services (Cummings)	O	O	O
Publications and Public Advisory Services (Sullivan)	O	O	O
COASTAL RESOURCES RESEARCH			
Predictive Methods and Information Systems in Coastal Zone Management (Twiss)	C	–	–
Physical Criteria for Coastal Planning (Inman/Winant)	O	C	–
Ecological Studies of the Nearshore Zone (Dayton)	C	–	–
Determination of Physical Changes of Southern California Coastal Lagoons (Phillips)	N/C	–	–
Oceanographic Inventory of the Southern California Shelf (Fischer/Berry)	N	C	–
Subtidal Ecology of Carmel Bay (Thompson)	N/C	–	–
Management of Beach and Dune Vegetation (Barbour)	N	O	C
Diving Safety Research Project (Egstrom)	N	O	C
Coastal Plan Preparation (Sullivan)	N/C	–	–
Management of Cumulative Impacts of Coastal Development (Dickert)	–	N/C	–
Issues of Coastal Governance (Lee/Scott)	–	N/C	–
San Francisco Bay Project: Reference Collection, Bibliography, Identification Keys and Specimen Depository (Lee)	–	N	C
Coastal Engineering Data Network (Isaacs)	–	–	N/C
Tilting Spar Directional Wave Sensor (Inman/Guza)	–	–	N/C
Coastal Wetlands Management: Biological Criteria (Holmes/Peterson)	–	N	O
Coastal Wetlands Management: Effects of Disturbance on Estuarine Function (Zedler/Mauriello)	–	–	N
Coastal Wetlands Management: Opening of Coastal Lagoons by Sand Fluidization (Inman/Nordstrom)	–	–	N
Longshore Sand Transport Studies (Inman)	–	–	N/C
Model Coastal Ordinance Project (Motley)	–	–	N/C
Development of a California Coastal Wetlands Information Directory for Resources Management (Dickert/Pepper)	–	–	N/C
Marine Resource Evaluation of Humboldt and Del Norte Counties, California: Preliminary Investigations (Isaacs/Kerstetter)	–	–	N/C
Geology, Faulting, and Related Seacliff Erosion, San Dieguito River to Carlsbad, San Diego County, California (Shepard)	–	N/C	–
Fiscal Impact of Park Acquisition in Laguna Beach (Dickert)	–	–	N/C
Transportation Analysis in the Coast Zone: Subregional Considerations for Local Coastal Plans (Dickert)	–	–	N/C
Physical Criteria for Thermal Discharges in Coastal Water (Winant)	–	N	O
Internal Waves Over Shelf and Canyon (Cox)	–	N	C
Assessment of the Offshore Commercial Sand and Gravel Potential on the Central California Continental Shelf (Berry/Wilde)	–	N	C
Methods for the Management of the Cumulative Impacts of Coastal Development (Dickert/Twiss)	–	N	C
Coastal Governance in California (Lee/Scott)	–	–	N/C
Half Moon Bay Private Sector Impact Study (Goldman)	–	N/C	–
Development of Interpretive Methods and Materials for Marine Parks in Northern California (DeMartini)	–	–	N
Development and Assessment of Legally Permissible Methods for Coastal Management (Heyman)	T*	–	–
The Potential Environmental Impact of the Japanese Alga, *Sargassum muticum* (Dayton)	–	N/C	–
AQUACULTURE RESEARCH AND DEVELOPMENT			
Economics of Aquaculture (Johnston)	O	C	–
Development of Aquaculture Systems (Shleser)	O	C	–
Use of Thermal Effluent in Aquaculture (Ford/Van Olst)	O	C	–
Protective Measures for Lobster Aquaculture (Schapiro/Steenbergen)	C	–	–

Project Title/Project Leader	FY75	FY76	FY77
AQUACULTURE RESEARCH AND DEVELOPMENT (cont'd)			
Seaweed Resource Management (Neushul/Coon)	C	–	–
Salt-Tolerant Plants (Epstein)	O	C	–
Development of a Commercial Aquaculture System for the Crab *Scylla Serrata* (Harrison)	N	C	–
Marine Ecology of the Central California Coast (Doyle)	C	–	–
Kelp Forest Ecology of the Central California Coast (Pearse)	C	–	–
Kelp Bed Mariculture and Resource Management (Neushul *et al.*)	–	N	R
Protective Measures for Shellfish Aquaculture (Schapiro/Steenbergen)	–	N	O
A Genetic Program for Improvement of Carrageenan in Red Algae *Gigartina* (West)	–	N	R
Effects of Public Regulations on the California Aquaculture Industry (Bowden)	–	N	O
The Development of the Science and Technology of Aquaculture (Hand)	–	–	N
Optimization of an Artificial Diet for Lobsters (Holtz)	–	N	C
Use of Thermal Effluent in the Culture of Crustacea and Fishes (Van Olst/Ford)	–	–	N
Biochemical and Genetic Control Applied to the Critical Stages in Culturing Abalone (Morse)	–	N	O
Surfperch Mariculture (Norris)	–	N	C
Aquaculture of the Purple-Hinge Rock Scallop (Phleger/Leighton)	–	N	O
Carrageenophyte Cultivation, Genetics, Population Dynamics, and Development of Agar Substitutes (Doyle/West/Abbott)	–	–	R
Toward Seawater-Based Crop Production (Epstein)	–	–	N
Astaxanthin from Yeast (Lewis)	–	N	O
The Role of Diseases in Aquaculture: Preliminary Survey (Raggi)	–	N/C	–
Plant Pathogens of Aquaculture Systems (Goff)	–	–	N/C
Bioeconomic Modeling of the Freshwater Prawn *Macrobrachium* spp. (Johnston)	–	–	N/C
Food Conversion Efficiencies of Instar Dungeness Crab (Tulles)	–	–	N/C
FISHERIES RESEARCH AND DEVELOPMENT			
The California Market Squid Fishery (Thompson/Frey)	N	O	O
Optimal Management of Sea Urchin Fisheries (Dayton)	N	O	R
Effects of Fishing Sea Urchins on the Marine Ecosystem (Connell)	N	O	R
Studies Toward the Optimal Management and Environmental Effects of Sea Urchin Fisheries (Dayton/Connell)	–	–	R/C
Determination of Appropriate Levels of Fees for Vessels Fishing for Yellowfin Tuna in the Eastern Tropical Pacific (Flagg)	N/C	–	–
New Antioxidants for Marine Lipids (Olcott)	C	–	–
Studies of Fish Muscle Proteins and Fresh and Frozen Seafood Technology (Brown)	N	O	C
Natural Fermentation of Marine Products (Crisan/Miller)	C	–	–
Histamine Toxicity from Fish Products (Olcott *et al.*)	N	O	C
Methods of Quality Assessment in Fishery Products (Chang)	–	N	C
Limited Entry: An Assessment for California Fisheries (Wyner/Harding)	–	N/C	–
Cause of the Decline in Dungeness Crabs in the San Francisco Bay Area (Horne)	–	N/C	–
Sand Bottom Community Structure and Artificial Reefs (Dayton)	–	N/C	–
A Study of the Santa Barbara Inshore Party Boat and Aspects of the Life History of the Olive Rockfish *Sebastes serranoides* (Ebeling)	–	N	O
Design and Development of a Squid Processing Machine (Singh)	–	N	O
Development of Trapping Methods for Migratory Salmonid Smolts in Hatcheries (Kerstetter)	–	–	N/C
Optimal Leasing Agreements for Marine Resource Development (Quirk/Lewis)	–	–	N/C
The Effects of Food Availability on the Growth and Survival of California Jack Mackerel Larvae (Mullin/Lasker)	–	–	N
Investigation of Data for an Economic Study of the U.S. Pacific Albacore Jig Boat Fishery (Holt)	–	–	N

Project Title/Project Leader	FY75	FY76	FY77
FISHERIES RESEARCH AND DEVELOPMENT (cont'd)			
An Ethnography of the San Pedro Wetfish Fishing Fleet (Velez)	–	–	N
Toxins from Marine Dinoflagellates (Rapoport)	C*	–	–
Mass Culture of Toxic Dinoflagellates (Haxo)	C	–	–
Marine Resource Management Intern Research Program (Sullivan)	C	–	–
Socio-Economic Aspects of Expansion of the California Swordfish Fishery (Holt)	–	–	N/C
Coordinated Management of the Pacific Coast Salmon Fisheries and the Implications of Extended Jurisdiction (Wyner *et al.*)	–	–	N
Protective Immunization of Anadromous Salmonids Against *Aeromonas salmonicida* and *Vibrio anguillarum* (Kerstetter)	–	–	N
Development of a Mechanism to Allow Release of Dungeness Crabs from Lost or Abandoned Pots (Jolly)	–	–	N
Endocrinology of Salmon Smoltification and Adaptation to Seawater (Bern)	–	–	N
The Social and Political Systems of the Tuna Fleet of San Diego and Ensenada: Their Place in International Cooperation and Competition for Marine Resources (D'Andrade)	–	–	N
NEW MARINE PRODUCTS			
Marine Natural Products Chemistry (Faulkner)	C	–	–
Seaweed Products: Application in Algae Control, Mariculture and Agriculture (Fenical)	N	O	C
Naturally Occurring Halogenated Compounds: Their Interference in Pesticide Pollution Analysis (Fenical)	N/C	–	–
Antiviral Compounds from Algae as a Potential Marine Resource (Vedros)	–	N	C
Marine Natural Products Chemistry of Fouling Organisms (Faulkner)	–	N	C
N = New Project			
O = Ongoing Project			
R = Restructured Project			

Project Title/Project Leader	FY75	FY76	FY77
NEW MARINE PROJECTS (cont'd)			
Development of Antiviral Compounds from Marine Algae (Vedros)	–	–	N
Development of Anticancer Substance from the Brown Seaweed *Dictyota* (Fenical)	–	N/C	–
Tissue Culture of *Macrocystis* and Related Seaweeds of Economic Importance (Lewin/Fenical)	–	–	N/C
Marine Plants as a Source of Insect Growth Inhibitors (Crews)	–	–	N
ENERGY			
Wave Climate Modification in Harbors by Dynamic Breakwater (Isaacs)	R	C	–
New Applied Developments (Isaacs)	C	–	–
Biological Effects of Waste Heat Effluents of Coastal Power Plants (Smith/Hand)	N	C	–
Stray Electrical Current Hazards to Prestressed Concrete Construction in Seawater (Cornet)	–	N	O
Earthquake Loading on Large Offshore Structures in Deep Water: A Study for the Correlation of Analytic and Physical Models (Wiegel *et al.*)	–	–	N
Seismic Hazards to the Development of Offshore Oil Resources (Prothero)	–	–	N
Power from Salinity Gradients (Isaacs)	–	N	O
Thermophilic Microorganisms Isolated from Undersea Hot Springs, Electric Power Plant Condensers and Ships' Heat Exchangers (Isaacs)	–	–	N
Placement of Underwater Mass Concrete by the Tremie Method (Gerwick)	–	–	N
Identification of Sources of Oil Spills in the Santa Barbara Channel (Profio)	–	N/C	–
Marine Vehicle Safety Analysis (Paulling/Webster)	–	–	N
RAPID RESPONSE			
Rapid Response Capability (Sullivan)	O	O	O
C = Completed Project			
T = Terminated Project			
*** = No Final Report**			

ACTIVITY BUDGET SHEET
1976-1977

	NOAA Grant Funds	Matching* Funds
MARINE RESOURCES DEVELOPMENT		
Aquaculture	431,146	503,535
Living Resources	97,237	109,441
Mineral Resources	5,018	5,754
Marine Biomedicinals & Extracts	66,333	27,873
SOCIO-ECONOMIC & LEGAL STUDIES		
Marine Recreation	10,129	17,968
Socio-Political Studies	29,864	8,317
Marine Economics	2,947	2,497
MARINE TECHNOLOGY RESEARCH & DEVELOPMENT		
Ocean Engineering	157,722	147,333
Resources Recovery & Utilization	100,626	122,421
MARINE ENVIRONMENTAL RESEARCH		
Research & Studies in Direct Support of Coastal Management Decisions	103,936	58,007
Ecosystems Research	110,544	59,874
Applied Oceanography	17,889	13,635
MARINE EDUCATION & TRAINING		
Other Education (Sea Grant Trainees)	305,748	37,548
ADVISORY SERVICES		
Extension Programs	324,027	220,148
Other Advisory	70,765	62,582
PROGRAM MANAGEMENT & DEVELOPMENT		
Program Administration	216,587	174,673
Program Development	69,482	25,818
TOTAL	$2,120,000	$1,597,424

*Includes $390,000 of state funds which were authorized in 1973 under Senate Bill 755 authored by Sen. John Stull, and recommended for matching funds by the Resources Agency Sea Grant Advisory Panel.

MATCHING FUNDS SOURCE
1976-77

Aquarium-Museum Docents
California Academy of Sciences
California Cooperative Oceanic Fisheries Investigation
Coastal Act Research Group
Counties of Sonoma, San Francisco/San Mateo, Monterey, San Diego, Ventura, and Marin
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San Jose State University
San Francisco State University
Scuba Pro Inc.
Southern California Edison
State of California
- California Coastal Commission
- Department of Fish and Game
- Department of Navigation and Ocean Development
- Department of Parks and Recreation
- Legislature Appropriation
- Resources Agency

Tuna Research Foundation
University of California

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Editor's note: Supplementary material and Trainee reports for individual projects are available at the Sea Grant Publications Office. See address below.

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Drawings by Christina Good, B.A., and Shannon Brownlee

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