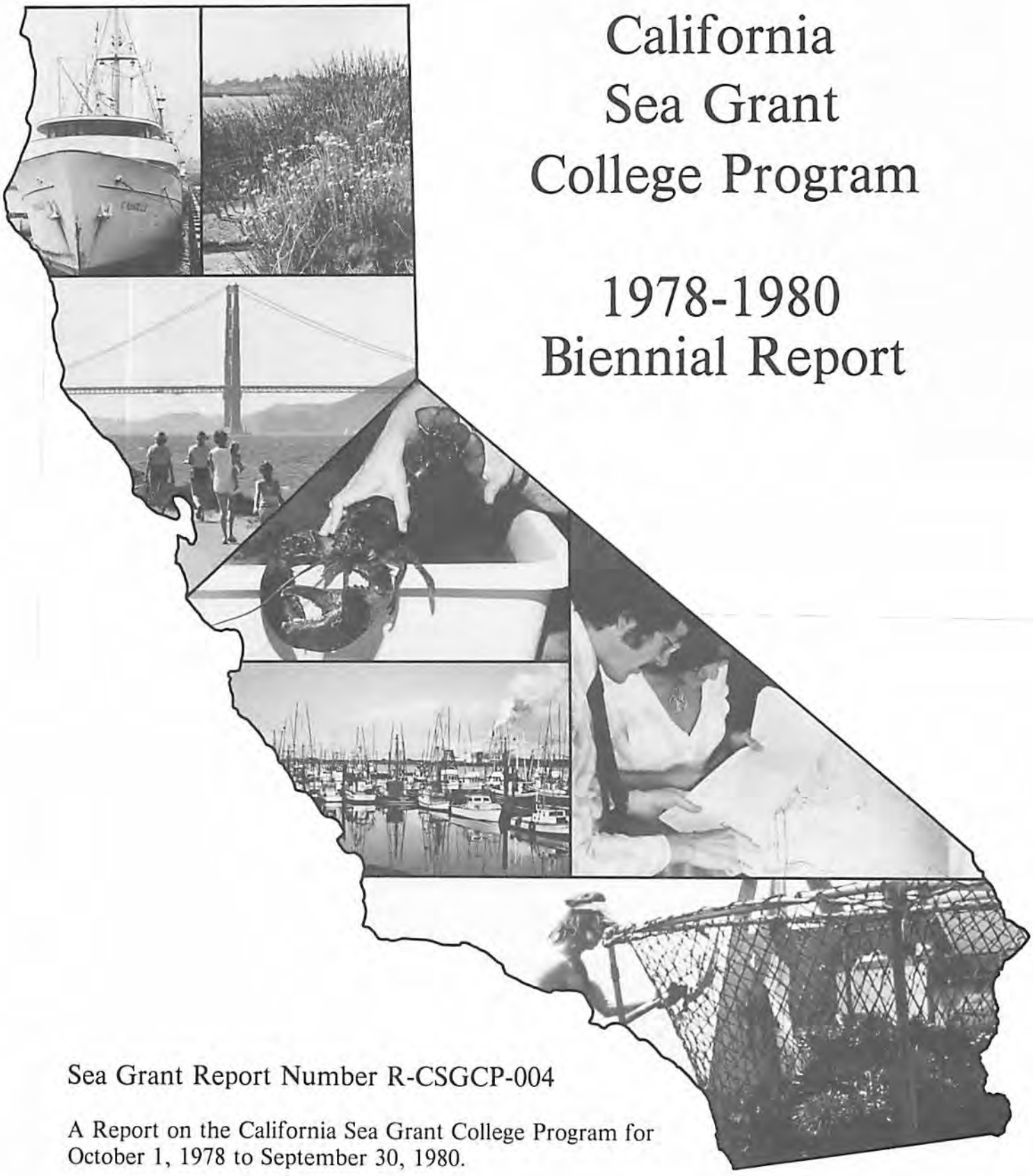

California Sea Grant College Program

1978-1980 Biennial Report

Sea Grant Report Number R-CSGCP-004

A Report on the California Sea Grant College Program for October 1, 1978 to September 30, 1980.

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Contents

Introduction

Sea Grant 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 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 eighty 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.

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 six University of California campuses (Berkeley, Davis, Riverside, San Diego, Santa Barbara, and Santa Cruz); California State University, Long Beach; 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; and Stanford. The philosophy of the program is to seek solutions to identified important local needs while fostering 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 directly involving state, regional, and local interests in the formulation of federal research and development priorities and in the conduct of the resulting programs. The strong partnership developed among 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.

This report on the California Sea Grant College Program, covering the fiscal years 1978-79 and 1979-80, contains brief technical reports on all of the projects the program supported during that period. Two companion booklets, written particularly for the general reader, are also available. *California Sea Grant College Program: A Summary, 1978-79* and *Using California's Marine Resources: A Summary Report on the California Sea Grant College Program, 1979-80* can be obtained from Sea Grant, University of California, A-032, La Jolla, California 92093.

James J. Sullivan,
Program Manager
January 1981

Education

Sea Grant Trainees

IMR-San Diego
E/G-2
1978-80

James J. Sullivan

Associated Staff:
Robert Holmes, Bernard Schweigert, Joy Zedler, John Martin, William Doyle, Robert Thompson

The primary functions of the University of California are, properly, education and research. Public service is an extremely important auxiliary function. The purpose of the Sea Grant Act closely matches the purpose of the university, since it also calls for education and training, research, and public advisory services. A major portion of the research of the university is carried on as an adjunct to the educational process; graduate students carry out the actual research under faculty guidance, with the dual purpose of performing significant research and satisfying the educational requirement of a master's or doctoral thesis. Many of the research projects described in this report were initiated by graduate students under the guidance of the faculty member listed as project leader. Others were initiated by a faculty member, one or more of whose graduate students became involved in the project and chose a portion of it for their own thesis work, carrying the major responsibility for completion. In other cases, students working on a Sea Grant project are acquiring skills and experience that they will need for their own thesis research. They are, therefore, the heart of the program and are acquiring their education while performing useful applied research in marine resources.

Since the first Sea Grant project at the UC San Diego campus in 1969 to develop the interdisciplinary Applied Ocean Science curriculum, graduate students have been heavily involved in the program. During that first year, nine graduate students were awarded Sea Grant traineeships; they assisted in setting up the acoustics laboratory and initiated independent practical research projects. These pioneering Trainees were the forerunners of the 411 who have followed. During the past two years we have awarded 144 traineeships at 13 California universities. The Trainees worked in such fields as agricultural economics, agricultural engineering, biology, biological oceanography, botany, ecology, environmental engineering, food science, geography, geology, history, home economics, marine biology, marine chemistry, marine science, microbiology, oceanography, and political science.

A few highlights from the California Sea Grant College Program illustrate the continuing utilization of the knowledge developed under the aegis of the traineeship project.

Larry Bell, a Trainee who earned his master's degree in food science and technology, still remains in close contact with the UC Davis food science group. Today he is a senior chemist at the headquarters of Del Monte Research Center in Walnut Creek, California. Prior to his affiliation with Del Monte, Bell was one of the UC Trainee/researchers investigating the histamine toxicity problem for the National Canners Association.

James Waldvogel, who earned his master's degree in fisheries science at Humboldt State University, is UC Marine Advisor for the Del Norte County, California, and Curry County, Oregon, area.

After earning his doctorate in economics on optimal production from a seaweed resource, Wesley Silverthorne, a former Sea Grant Trainee, is currently an economist with the National Marine Fisheries Service at the Terminal Island Office.

Michael Orbach, a Trainee in anthropology, conducted much of his Ph.D. thesis research aboard tuna vessels sailing out of San Diego. After completing his thesis on the tuna fleet, he became the Social Anthropologist for the Fisheries Management Division of the National Marine Fisheries Service in Washington, D.C. He is now Associate Director of the Center for Coastal Marine Studies at UC Santa Cruz.

As an Applied Ocean Science Trainee, Richard Seymour worked with Professor John Isaacs to develop the original tethered float breakwater. Seymour is now Staff Oceanographer for California Department of Boating and Waterways and liaison to Scripps Institution of Oceanography. He has continued research under the auspices of California Sea Grant and is the project leader for the Nearshore Sediment Transport Study--a Sea Grant National Project.

Having received her Ph.D. in phycology as a Sea Grant Trainee, Judith Hansen is a research biologist at the Hopkins Marine Station of Stanford University. Presently, she is conducting Sea Grant research on the aquaculture of red algae.

Maynard Silva received his Ph.D. in political science at UC Santa Barbara and is presently a postdoctoral Ocean Policy Fellow at Woods Hole Oceanographic Institution.

After receiving his Ph.D. in botany from UC Berkeley, Arthur Nonomura has taken a position with the International Plant Research Institute in San Carlos, California. He writes, "As a result of the Sea Grant-sponsored training, adding breadth of intellect and acquaintances, I found myself in a rare position: as a job-seeking biologist, I had several jobs to choose from at relatively high salaries."

James Hunt, a Trainee at California Institute of Technology, received his Ph.D. in environmental engineering. He is currently Assistant Professor of Engineering in the Division of Sanitary, Environmental, Coastal and Hydraulics Engineering at UC Berkeley.

Further information on the results of research accomplished by other students is reported under the individual projects.

Marine Education: Undergraduate Independent Research

William T. Doyle

This two-year "pilot project" placed undergraduate students as interns in public and private agencies concerned with marine resource issues. The program's objective was to increase the pool of qualified investigators working on marine resource problems by introducing trained and highly motivated undergraduate students to possible marine-related career opportunities early in their university education. The internships were open to students in the natural sciences and social sciences. The program gave students the opportunity to use academic skills on contemporary marine social science problems and, on completing the internships, to return to campus for additional academic work and interaction with other students.

Procedure

The Environmental Studies Program at Santa Cruz has a very successful internship placement program that was used for this project. Ms. Jennifer Anderson, who heads the program, asked faculty for names of agencies for potential student placements, and she was aware of additional possibilities through previous interactions. The agencies were asked to return a form indicating the kind of research internships available through them, duration of the internships, and the qualifications expected of the student. Students and faculty were free to make individual contacts with agencies, but in all cases the agencies had to fill out the appropriate form. A faculty committee (Drs. Sue Holt, Jerry Bowden, Richard Cooley, Dudley Burton, Jim Pepper, and Bill Doyle) evaluated all internship requests for academic merit and relevance to Sea Grant goals.

Internship opportunities were then widely advertised on campus (class announcements, posted notices, contact with individual students,

Table 1
Undergraduate Research Internships 1977-78

Agency Sponsor	*Student*	*Topic*	*Faculty Sponsor*
Marine Mammal Commission and Alaska Center for the Environment, AK (Peg Tileston)	David Benton Biology/Environmental Planning	Conflicts between OCS Development and Marine Sanctuary Status in the Beaufort Sea	Richard Cooley
Sea Grant Marine Advisor, Santa Cruz and Monterey Counties (Jim Waldvogel)	Scott Cooper Economics	The Economic Value of the Partyboat Fishing Industry in Monterey Bay	Sue Holt
California Coastal Commission, San Francisco (Eric Metz)	Mark Stevenson Environmental Studies/ Biology and Susa Gates Environmental Planning/ Biology	Regional Workshops on Coastal Wetlands	Jim Pepper
UC Santa Cruz	Jane Stanley Earth Sciences and Barbara Evoy Earth Sciences	Legal Controls Governing California Coastal Aquaculture Industry	Gerald Bowden
National Marine Fisheries Service, Tiburon, CA (Ed Ueber)	Aurora Belarmino Economics	Economic Aspects of the Drag Industry	Sue Holt
National Marine Fisheries Service, La Jolla, CA (Dan Ruppert)	Gregg Pottorff Physics/Economics	Problems with Multiple Stocks in Fisheries Management	Sue Holt

Undergraduate Research Internships: 1978-79

Agency Sponsor	*Student*	*Topic*	*Faculty Sponsor*
California Department of Fish and Game, Sacramento (E.C. Greenwood)	Terry Whisler Environmental Studies/ History	Analysis of Current Aquaculture Legislation	Dudley Burton
National Marine Fisheries Service, La Jolla, CA (June McMillan)	Dennis Fitzpatrick Environmental Studies/ Economics	Aspects of the Economics and Social Structure of the San Diego Market Fish Industry and its Relationship with the Fish Stock Resources	Dudley Burton
California Coastal Commission Santa Cruz, CA (William Leland)	Karen Delaney Environmental Studies/ Politics and Peter Meshot Biology	Evaluation of OCS Drilling in Central and Northern California	Dudley Burton and Donald Potts
Friends of the Earth, Alaska (Ben Shaine and Margie Gibson)	Suzanne Easton Environmental Studies/ Biology and Mary Ellen Spencer Environmental Studies/ Biology	Evaluation of Marine Bird and Mammal Data of the Environmental Report on OCS Leasing in the Shelikof Strait Area of Alaska	Richard Cooley
National Marine Fisheries Service, Terminal Island (Wesley Silverthorne)	John Sheldon Environmental Studies/ Economics	Survey of Construction of Commercial Fishing Vessels	Sue Holt
National Oceanic and Atmospheric Agency, Boulder, CO (Robert Parentinos)	Kurt Mize Biology/Environmental Studies	Review of OCS Environmental Impact Statements from Alaska	Richard Cooley

etc.). Students filled out an application form indicating--among other things--class level, relevant course work and other experience, and name of faculty sponsor. The faculty committee with Ms. Anderson evaluated the applications, matched students with internship requests, and selected students.

Upon completion of the internship, students were expected to return to Santa Cruz for one quarter or longer. This permitted us to meet with them to evaluate their experience, allowed students to use their experience to more sharply focus their subsequent academic course work, and provided opportunities for them to interact with other students, including potential future interns. In this way the Sea Grant Program became known to a wider segment of the student body than otherwise would have been possible. Year one students, in addition, presented an afternoon symposium the fall quarter following their return to campus. Year two students gave a series of noon seminars during the fall quarter following their return. In addition, members of both years gave presentations in individual classes.

Results

Students were placed in a wide variety of agencies. Table 1 lists research internship placements, faculty sponsor, and topics of study.

The Undergraduate Research Internship Program has enabled good students to become involved in marine-related research in the social sciences; it has made students aware of new career opportunities, and these students, upon return to campus, informed other students about these opportunities; it has resulted in students more sharply focusing their educational programs upon returning to campus; and it has resulted in a heightened awareness of both the national and state Sea Grant Program by students, faculty, and public and private agencies.

A History of the Santa Barbara Channel

UC Santa Barbara
E/UG-2
1979-80

John Talbott

The goal of this project is to identify and collect data on the history of the Santa Barbara Channel and to prepare a course syllabus on the Channel's history. In the past year I have identified and gathered evidence for the earliest period of this study--the nineteenth century. In addition to conducting research in Santa Barbara libraries, I have made research trips to investigate sources in the National Maritime Museum in San Francisco; the Bancroft Library of the University of California, Berkeley; and the National Archives, the Archives of the Smithsonian Institution, and the Library of Congress, in Washington, D.C.

My trips to San Francisco turned up some data that will be useful not only in this project but in future projects in marine history, but the National Maritime Museum's holdings on the Santa Barbara Channel in particular were disappointingly thin, especially its photographic sources.

The National Archives in Washington, however, contained more data relevant to the Channel's history than I was able to exploit in six weeks of summer research, and I hope to make one more trip to complete my work there. I mainly consulted Record Group 16, the records of the Coast and Geodetic Survey--or Coast Survey, as it was known in the early decades of its existence. In the nineteenth century the Coast Survey was the largest scientific enterprise of the federal government. My main interest in this record was in the correspondence between Alexander Bache--the head of the Coast Survey in the 1840s, 50s and 60s--and his assistants in the field, the most notable of whom was George Davidson.

This correspondence clearly shows the federal government's intense interest in the waters of the Channel from the earliest moment these waters came under the jurisdiction of the United States. Already in 1849, a hydrographic and topographic party was sent into the Channel to make accurate charts of its waters and coastline. In 1850 George Davidson established a surveying station on Point Concepción, and recommended the establishment of a lighthouse there.

So far as I am aware, no one has ever used the papers of the Coast Survey for the purposes to which I am putting them. I am making copies of some of these holdings, and I plan to encourage students who will take my course on the Channel to work with these primary historical materials.

The Smithsonian Institution archives also proved rewarding, though their holdings are not as large and important as those of the National Archives. At the Smithsonian archives, I concentrated mainly on the papers of Joseph Henry, who was the first secretary of the Lighthouse Board; on the papers of Stephen Baird, another Smithsonian administrator and the supervisor--from Washington--of the first anthropological research (something of a travesty, as it turned out), to be conducted in the Channel Islands; and on the papers of the Lighthouse Board.

The unexpected richness of the National Archives holdings on nineteenth-century federal involvement in the Channel has caused me to postpone research on the whole question of energy exploration and exploitation, which is primarily a twentieth-century subject. For it I intend to rely mainly on interviews and on the extensive holdings of UC Santa Barbara. I have continued to read in the most extensive literature in the field of fishing and fishermen--that on the New England fisheries--for applications that might be made to the Santa Barbara fishery.

Cooperating Organizations
Atlantic Richfield Oil Company
Environmental Resources Office of Santa Barbara County

Ocean Engineering in the Future: Long-Range Planning (A Graduate Seminar)

William C. Webster and Marshall P. Tulin

This graduate-level course was developed as an independent studies seminar and met for two hours each week during the ten-week period of the spring quarter 1980 at the University of California, Berkeley. The seminar was entitled, "Ocean Engineering—The Future," E201.

We set out to accomplish a number of goals during the seminar:

1. To look at the prospects and possibilities for ocean engineering in the future
2. To expose students to the opinions and enthusiasms of leaders in the engineering profession actively involved with various facets of ocean engineering
3. To give students a taste of the process involved in reacting, within a short time span, to a request for a technical proposal
4. To offer students, as members of a small team, the experience of carrying out short-term research and feasibility studies, including the preparation of both oral reports and a final written report documenting their work. Accordingly, the seminar was divided into the following parts:

I. Lectures, readings, project generation
II. Proposal preparation and presentation
III. Project preparation and progress presentations
IV. Final presentations, including written reports

A collection of technical papers, including surveys, in the field of ocean engineering were reproduced and distributed to each student at the first meeting. In addition, a substantial collection of relevant papers was made prior to the seminar and kept available for student reference throughout the quarter. These were on a wide variety of subjects, including futurism--the oceans; technological forecasting; the future marine environment (trade, world resources, etc.); law of the sea (pollution, etc.); story of the seabed and seafloor exploration; minerals from the sea; marine mining; energy from the ocean; biological potential of the coasts and oceans (mariculture and aquaculture); hydrocarbon potential of the sea; polar ocean engineering; ports and offshore terminals; artificial islands; ocean structures; future ocean vehicles; underwater and subsea engineering; undersea systems (submersibles, manned dwellings, etc.); man in the sea; deep water production.

At the first meeting, a Request for Proposal was presented to the participants inviting proposals for studies "concerned with ocean engineering to meet specific future needs" and involving "evolution of existing engineering systems or concepts, new engineering concepts, exploitation of fundamental engineering innovations or scientific breakthroughs." Ten proposals were presented orally at the fourth meeting. Of these, six were selected for completion.

We were fortunate to attract as guest lecturers some outstanding engineers, and their lectures proved popular not only with the students but with others on campus. These lectures were particularly important during the proposal stages of the work. Lecturers and their topics were: Mr. Bengt Lachmann, "Eurocean--The European Way to Ocean Industries"; Mr. Marshall Tulin, "Ocean Engineering--The Future" and "Wave Energy"; Mr. Clinton E. Brown, "Engineering Ocean and Thermal Energy"; Professor Ben Gerwick, "Ocean Structures--Current and Future Developments"; Professor John Craven, "Ocean Cities, OTEC, and Other Ocean Challenges"; and Dr. Dayton Alverson, "Ocean Engineering and Food from the Sea."

The students' response to the project work was extraordinary. They each made serious and enthusiastic attempts, and in a number of cases produced interesting results worthy of further study.

Cooperating Organizations
IBM Foundation
Interdisciplinary Studies Center, UCB

Advisory Services

Marine Advisory Program

Maynard W. Cummings

The major goals of this project are to provide educational opportunities concerning California's ocean and coastal resources to the state's citizens, particularly those who are users of this resource wealth; to assist those who make decisions regarding uses of these resources; to identify and help solve marine resource use problems; and to continue to develop and improve staff capabilities to accomplish these objectives.

In January 1979 an area marine advisor was located in Crescent City to serve Del Norte County, California, and Curry County, Oregon. The Oregon Marine Advisory Program pays 25% of the position support. This advisor provides much-needed services to fishery industries in the ports of Crescent City, Brookings, and Gold Beach and to other audiences in this remote stateline area.

Two marine advisors were given specialist designation to provide statewide assistance in their specialties while continuing their area advisory programs as their primary roles. Barbara Katz is now Ports and Transportation Specialist, and the San Francisco Bay Area Marine Advisor is designated as Coastal Resources Specialist. Through an agreement with California State University Long Beach, Barbara Katz's office was located on that campus in January, 1980. This has provided valuable contact and support for Sea Grant research as well as advisory services from CSULB and other southern California state universities. The Monterey/Santa Cruz Counties area advisor was hired in September, 1980, and a new Humboldt County advisor reported in January 1981.

A number of special publications were prepared in addition to two monthly statewide newsletters from the specialists, and individual local monthly newsletters distributed by the marine advisors. These, plus workshops are our major means of sharing information. The individual contacts made by marine advisors directly with their constituencies remain the most important factor in applying Sea Grant knowledge where it is needed.

Numerous workshops and training meetings were held with all areas emphasizing fisheries. There were management meetings, workshops on trawling and other gear development subjects, salmon and steelhead information, and various fisheries economic subjects. Several *fishermen's groups* were given assistance and information on formation of co-ops, and a Cooperative Extension economics specialist supplied technical information.

Workshops were presented in seafood processing plant sanitation, and individual processors were assisted with current procedures and techniques. A food microbiology short course and two food canning short courses were given. Two workshops were presented on salmon quality and marine refrigeration, and one short course each was presented on sensory evaluation and quality management. Individual processors were assisted with specific waste management problems. Information on new and improved processing and handling techniques was distributed to the seafood industry through newsletter items. Individual processors were assisted in developing in-house training materials. A videotape training program was prepared on plant sanitation. Information on home processing of seafoods and on seafood safety and nutrition was provided to consumers and food editors through county staff and numerous personal contacts. A leaflet, "Smoking Fish at Home," was rewritten and expanded. Five consumer seafood workshops were presented. Three slide-tape sets--"Smoking Fish," "Freezing Seafood," and "Canning Fish"--were prepared in English and Spanish.

Information on the Marine Advisory Program was distributed to all 775 licensed seafood processors in California. A summary of current seafood research projects being conducted in the United States was prepared and distributed to the seafood industry. Information and assistance was given to the Department of Health Services and the seafood industry to publicize, explain, and limit the effects of this year's paralytic shellfish poison outbreak. Through research, public service, and Marine Advisory activities, UC Davis has come to be regarded as a leading source of technical information on modified-atmosphere storage of seafood.

A research forum in ports and transportation was held, and the proceedings were written and distributed. A new audience made up of port and harbor managers was contacted this year. Their problems are being defined and contacts developed. It is obvious that they have serious problems of management and dock deterioration from weathering and marine borers. A program is under way to define the marine borer problem and recommend procedures to eliminate major

dock deterioration.

Educational information was provided to local coastal planners concerning fishery and aquaculture coastal problems. Assistance and information was given to the California Coastal Commission and Regional Coastal Commissions regarding coastal recreational access, offshore oil drilling, wetlands management, port and harbor development, aquaculture siting and needs of marine aquaculture industries, and ocean ranching of salmon.

The oyster industry was provided with information on financial assistance programs offered by the USDA-Farmers Home Administration during and after the California outbreak of paralytic shellfish poisoning. Three companies are applying for financial assistance loans.

Marine aquaculture industries were informed about industry grant programs, and industry-university advisory panels were established for industry development assistance and feedback to university researchers.

Assistance was given to fishermen interested in black cod, rockfish, skate, sea urchins, octopus, sharks of various species, and other underutilized species. In cooperation with the West Coast Fisheries Development Foundation, research results of experimental blue shark long-line fishing are being analyzed, and in other blue shark research by a Marine Advisory Specialist with UC Davis engineers, a shark skinning machine was tested.

Two Fort Bragg trawlers are supplementing their traditional deliveries of dragfish with dressed Pacific whiting. This is significant because it may be the beginning of a new U.S. fishery that has the potential for leading all other fish landings in the Fort Bragg-Eureka area.

Reports were made to the marine advisor about a pile of mud running for several miles alongside a pipeline that runs through a major shrimp trawl ground in the Santa Barbara Channel. The marine advisor set up a meeting with USGS, BLM, area trawl captains and the responsible oil company. Input to USGS from area trawl fishermen has resulted in the removal of some abandoned submerged wellheads (under federal jurisdiction) in the Santa Barbara Channel.

The Marine Advisory Program is continuously called on to supply information or advice to a broad spectrum of "marine clientele." Seafood processors ask for marine biology or catch information or labeling information or suggestions on waste disposal. Consumers and newspaper writers ask about seafood biology and technology. (What species occur where, or can be eaten, or how long can a fish be refrigerated and still be edible?) Landowners or investors or students request aquaculture information. Commercial fishermen ask about taxes or financing or licensing charges or fishing information. Public Health authorities request specific biological information.

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Cooperating Organizations

California Coastal Commission and Regional Coastal Commissions
California Department of Boating and Waterways
California Department of Fish and Game
California Department of Food and Agriculture
California Department of Health Services
California State Lands Commission
Cal Poly San Luis Obispo
Cal State Univ. Long Beach
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
Moss Landing Marine Laboratories
National Environmental Data Service
National Marine Fisheries Service
National Weather Service
San Diego State University
San Jose State University
Univ. of Calif., Berkeley
Univ. of Calif., Bodega Marine Laboratory
Univ. of Calif., Cooperative Extension
Univ. of Calif., Davis
Univ. of Calif., Division of Agricultural Sciences
Univ. of Calif., Irvine
Univ. of Calif., San Diego
Univ. of Calif., Santa Barbara
Univ. of Calif., Santa Cruz
Univ. of Southern California
U.S. Bureau of Land Management
U.S. Coast Guard
U.S. Corps of Engineers
U.S. Forest Service
U.S. Geological Survey

Communications, Publications, and Public Advisory Services

James J. Sullivan

Associated Staff:
Louise F. Eklund and Kenneth V. Cobbs

Sea Grant produces and has access to a wealth of marine-related information that has potential value to a wide range of audiences--from the scientist or technical researcher to the citizen who participates in making decisions about use, management, and development of coastal and ocean resources. How best to convey that information in a timely and useful fashion to those who need it is a continuing challenge.

The overall objective of this project is to establish, implement, and continually refine for the California Sea Grant College Program a systematic means of identifying audiences and their information needs, of producing high-quality publications and other products, and of organizing and selectively disseminating information.

We have progressed toward this objective through careful review of activities of the former publications project, refinement of some of those activities, and establishment of a foundation for future efforts.

In 1980-81 our primary objective was to establish a foundation for the program's communications effort in two key areas: publications policy and computer-based information management. In both areas, significant progress has been made.

The Publications Policy and Review Committee, appointed by the program manager, prepared a policy outlining publications philosophy and procedures for project leaders and other Sea Grant authors. The policy provides clear guidelines for authors as well as an objective framework for considering potential publications. This becomes ever more important as publications costs continue to rise.

Information management needs of the program were identified, and priorities for meeting them--through computer processes, where appropriate--were defined. The first phase of this activity has focused on the financial aspect of information management. Computer assistance with financial management and accounting procedures has become essential as the Sea Grant Program in California has grown. Redefinition of one staff position to include computer programming duties; acquisition of computer peripheral equipment; and establishment of links to existing computer facilities were the necessary initial steps to begin converting the financial management and accounting procedures from manual to computer-assisted functions. This conversion, which will be largely completed by September 1981, has already increased the efficiency and effectiveness of this aspect of program management.

The second phase of this activity focuses on publications production and information dissemination. The communications secretary has been trained in the use of an electronic typewriter, a CRT terminal, and a Diablo printer for use in producing publications. She also has learned use of a text editor, through the UCSD computer services, for editing and typesetting original manuscripts with relative ease. This new capability will significantly reduce publications costs in the future. By September 1981, the program's mailing list will be computer-indexed for rapid identification of various special audiences.

The combination of a formulated policy and procedural guidelines for publications production and the appropriate equipment for word processing and information management tasks makes the next steps in communications planning and development possible.

In other areas, we have evaluated past activities and procedures and revised them when necessary. For example, we have redesigned the program's annual report to serve the needs of multiple audiences. Previously, it served only those audiences interested in technical information on all of the Sea Grant projects funded through the California Sea Grant College Program in a given year. This extensive technical report is now published on a biennial (rather than an annual) basis and is supplemented by annual program summaries, written in a nontechnical but informative style.

For a number of years, interns from the science writing program at UC Santa Cruz have worked with Sea Grant to produce a topical report series. We are now extending the information contained in these reports by adapting and formatting it for different audiences or by

selectively distributing the reports to individuals or agencies who are in a position to use them for educational or informational purposes. For example, a three-fold leaflet on coastal wetlands was extracted and adapted from *California's Coastal Wetlands*, supplemented with recommended classroom activities, and included in a mailing of the State Department of Education to 10,500 public schools in the state. The report series is distributed to the news media for use as background information or as the basis for feature articles. The most recent report in the series, *California's Salmon Resource*, is being used by the chief of the anadromous branch of the California Department of Fish and Game to educate field personnel on salmon issues and topics.

Publications

Sea Grant/IMR Series

Feinberg, L. and T. Morgan. *California's Salmon Resource: Its Biology, Use, and Management.* Sea Grant Publication No. 72, Sea Grant Report Series No. 3, 38 pages (1980).

Ingmanson, D., and L. Eklund, eds. *California Sea Grant College Program: A Summary 1978-79.* Sea Grant Publication Number 71, IMR 80-101, 37 pages (1980).

Sea Grant Reference Series

California Sea Grant College Program. *California Sea Grant College Program Directory 1980-81.* Sea Grant Reference Series No. R-CSGCP-001, 65 pages (1980).

Ocean Education for the Public

UC San Diego/UC Santa Barbara/
UC Santa Cruz/Moss Landing/Humboldt State
A/PE-1
1978-80

Donald W. Wilkie, Patricia A. Kampmann, David Coon, William T. Doyle, Michael S. Foster, B.A. Stewart, John D. DeMartini

Scripps Institution of Oceanography, UC San Diego

This project is designed to increase and enrich public awareness of the world's oceans and the California coastal zone through education programs, museum exhibits, and information services. The key target group is today's school children, who will be tomorrow's voters and decision makers.

Since 1970, the first year of Sea Grant support for the education program at Scripps, a formal field trip program with educational materials at six grade levels has been developed and expanded for school groups. An outreach program taught by aquarium-trained docents is offered for schools unable to travel to the T. Wayland Vaughan Aquarium-Museum. The teaching units range from one hour to courses of several weeks' duration. In addition, the Aquarium-Museum offers teacher training courses, career experience for high school students, and special classroom science education for minority students and gifted students. Advisory assistance is provided to teachers and school districts in designing courses concerning marine science education and conservation of California resources. During the past year we have concentrated our efforts on the following areas:

Educational materials. We undertook a major revision of the educational materials mailed to teachers participating in the Aquarium-Museum field trip program. These materials are available at four levels (pre-K, 1-2, 3-4, 5-6 grades) for elementary students. For teachers, Part II of *Living in a Watery World* was completed. A 30-page workbook, "Fishes, Shore Birds, and Marine Mammals" was developed for the 14-hour weekend course offered last spring. This workbook, along with Part I, "Tidepool Inhabitants," is being evaluated by teachers.

School field trips to the Aquarium-Museum. All field trip programs in California are in a state of flux, because of the results of Proposition 13 and court-ordered busing for desegregation. We are pleased that Aquarium-Museum field trips are holding steady at more than 41,000 students per year, indicating strong continued teacher interest and commitment. Out-of-state travel education is showing an increase. Many Tucson and Phoenix, Arizona, schools come regularly, as do their teachers for our teacher training courses. Salt Lake City, Utah, sent 600 students last year from Utah and Montana.

Docent training program. Docents are trained guides who work with the large numbers of field trip students mentioned above. The docent training program has been expanded to a two-and-a-half-month lecture and laboratory course with slides, films, living and preserved specimens, and field trips. Monthly lectures by staff members provide continuing training and information. A ten-dollar fee helps defray expenses for printed materials and biological specimens.

Outreach programs. Because many schools are unable to make field trips to the Aquarium-Museum, the docents traveled to more than 50 schools where they offered 1,500 students 1-2 hour lessons in marine science. Longer units

(Photo courtesy of Scripps Institution of Oceanography.)

were designed for several school districts. For instance, Chula Vista requested and received eleven 2-5 day courses for its students. Rancho Santa Fe parents ran a four-week summer school (most California summer schools were cancelled because of lack of funding), in which we taught two courses: a third, fourth, and fifth grade tidepool class and a sixth, seventh, and eighth grade oceanography class.

Mentally Gifted Minor Program. Our participation in this state-mandated program for gifted students was requested for the third year by 15 schools. The five-day course is taught by an Aquarium-Museum docent with California teaching credentials. The course uses our slides, live and preserved specimens, and worksheets, and is paid for by state funds.

ESAA. Emergency School Assistance Aid is a federal program for schools acting under court-ordered desegregation rulings. Three docents traveled to minority schools and offered special units in marine science. The three-day courses were taught to 18 classes in six schools. They were so successful we have been asked to expand the program next year.

In-service training for teachers. Teachers keep requesting additional training courses to augment their information. Our tenth annual day-long symposium, "Energy from the Sea," was given in the winter. "Living in a Watery World, Part I, Tidepool Life," was a weekend course given in the fall. Part II, "Fishes, Shore Birds, and Marine Mammals," was completed and offered in the spring, and included the 30-page workbook. These are both under evaluation by teachers from San Diego, Los Angeles, and Arizona.

Oceanography mini-courses. During the summer, we are able to offer more intensive courses from one to six weeks long. Ten of these courses are given in 20 sections to 500 students from first grade through high school. Fees charged pay for salaries and materials, and also provide income for Aquarium-Museum education projects such as films, filmstrips, lab kits, etc.

Career experience program. During the summer, we offered an intensive six-week course for eight high school students who are considering a career in marine biology or aquariology. This course, with fees of $150 per student, combines lectures, labs, field work, and independent assignments. Scholarships from service clubs cover the costs of students unable to pay the normal fee.

Junior Oceanography Corps. Over a hundred families participated in this organization for fourth grade through high school students. Monthly lectures by Scripps scientists and weekend field trips in ocean-related areas are presented.

San Diego-La Jolla Underwater Park guides. Docents participated in our annual tidepool patrol to provide information to the public and to encourage conservation and protection of the intertidal environment.

Advisory services. Staff members replied to requests both written and verbal on a wide variety of marine subjects, from scientific investigation to maintaining aquaria. We assisted teachers and school districts in developing marine courses, worksheets, and teaching materials. In addition, slides, films, and filmstrips are loaned to teachers and speakers for a modest fee. We also consulted with the National Geographic Society about content and photographs for their children's book on the sea.

Marine Science Institute, UC Santa Barbara

The Marine Science Institute at UC Santa Barbara annually hosts visitors on special tours at the campus Marine Laboratory. These tours are scheduled for four days at the end of each academic quarter, when marine laboratory classroom space is not in use. "Community" groups (some travel more than a hundred miles to reach the lab) are given tours in small groups, under the guidance of UCSB undergraduate and graduate students. In the past two years, we have had over six thousand visitors, primarily school groups ranging from preschool to twelfth grade, including handicapped as well as gifted.

Extensive diving collections of local organisms are used to create displays that accurately represent the diversity of the local environment. The displays include large touch tanks, microscope demonstrations, large outdoor tanks, and displays of field research equipment. The student docents are given an orientation session in which the topics and areas of emphasis are defined. They are also encouraged to discuss their own marine science interests, as appropriate.

During the past year, evening sessions were held for the fist time, in order to reach a larger segment of the community. These evening sessions were successful both in terms of community response and for the students, who had an opportunity to deal with adult groups.

All groups are sent preparatory materials before their visits, and are offered a self-guided

(Photo courtesy of University of California, San Diego.)

beachwalk guide for the local beach area at the end of their tours. The beachwalk guides are also offered to "drop-in" visitors to the campus throughout the year.

A similar tour program was set up and conducted for University Day, the campus open house held annually in April, and for Staff Recognition Week, held in May.

After the tour program, groups are provided with evaluation forms. The information obtained from these responses has enabled us to continually improve the program and to assess its impact.

Center for Coastal Marine Studies, UC Santa Cruz

The majority of the year was spent in evaluation, review, and restructuring of the program. The major events and changes that occurred are as follows:

1. We applied for and received funding from The Nature Conservancy to review and evaluate the Elkhorn Slough Program. We decided to incorporate it into the Ocean Education Program and now offer slide shows about the field trips to the Slough. This will broaden our educational offerings and, we hope, attract more Mexican-American interest both in students involved and public served. The field trips are taken on Nature Conservancy land, and we have the Conservancy's support for the program changes.

2. We submitted to the Curriculum Committee of the Environmental Studies Board proposals for two new courses that would strengthen the program by offering students more academic and interpretive preparation. ES 179, Environmental Interpretation, was approved and taught for the first time in the spring of 1980. It was a tremendous success and had a noticeable effect on the quality of the students' interpretive tours. ES 116, The Natural History and Human Uses of Elkhorn Slough, has been changed to The Natural History of Monterey Bay, and a section of the course will focus on saltwater marshes. This course will provide the primary academic training for the Elkhorn Slough interns.

3. We applied for and received an Instructional Improvement Grant to offer a seminar series on the natural history and human uses of Elkhorn Slough. This was to be the forerunner of the ES 116 course (which was changed as mentioned above). The series was very successful and had significant participation from outside agencies.

4. We applied for and received an Instructional Improvement Grant to develop a reader for the Environmental Interpretation class.

5. With Moss Landing Marine Laboratories, we discussed ways we could offer joint educational programs to the public. They participated

in our seminar series, and we shared curricular and resource materials. This will, no doubt, be an extremely important connection in the future of the program if we continue to work at Elkhorn Slough.

6. We looked into the possibility of a cooperative program with Long Marine Lab. We felt that field trips to the Lab and the intertidal area of Natural Bridges State Park would complement each other and that groups could be directed to the Lab in rainy weather or bad tides. Student docents or interns would be involved in one or both programs.

7. We developed a new administrative format for the program. We felt that an administrator who would be responsible for coordinating activities, serving as a liaison to agencies involved, and training and supervising interns should be hired to oversee all of ocean education during the fall, winter, and spring. Interns would then be involved only in interpretive work and would not be responsible for coordinating and administrative functions, as in the past. All participating students would be interns who are receiving academic credit for their work. The position of guide, a student paid to give tours, has been eliminated. During the summer, the Natural Bridges Program will be run by former interns who will be paid for their administrative and interpretive work.

8. We changed the program format so that the Natural Bridges State Park Program will be offered year round, but the Elkhorn Slough Program will be offered only in the spring.

9. We developed a new format for recording statistics so that we could get some information on who we were serving, and where they came from and found that:

a. We are reaching more people with fewer students involved. This is, in large part, due to the new administrative structure, which frees the students to concentrate all of their time on interpretive contacts instead of dealing with time-consuming bureaucratic work.
b. Great numbers of our visitors come from the Santa Clara Valley.
c. During the spring, we have primarily K-6 groups. In the summer, we made a concerted effort to involve more adults, and the mix was more even.

Moss Landing Marine Laboratories (MLML)

The overall goal of MLML's Ocean Education for the Public program is to increase public understanding of marine science and coastal marine environments. The following activities were carried out to achieve this goal:

MLML Visitor Days. Over 800 students from private and public schools attended Visitor Days each year. Several stations were set up, including a touch tank area; a holding tank with large invertebrates, sharks, and other fish; a plankton room with sampling equipment and microscopes; a room with diving equipment displays, aquaria representing local marine communities and representatives of local mariculture organisms; and a marine geology display.

Response to the 1980 Visitor Days invitation was so great that within four days of mailing, all the slots were full, and about an equal number of groups were turned away. Visitors represented a cross section of Monterey Bay student population. Ages ranged from preschool to high school, and several handicapped groups attended, including aphasic, hearing impaired, physically handicapped and mentally retarded. A variety of economic and cultural backgrounds were represented; some classes were bilingual. Large groups were broken down into subgroups of ten each and led through the various stations by an MLML graduate student.

Evaluations and thank-you letters from teachers and students indicated that the Visitor Days program was both enjoyable and educational. Previsit materials were sent to the teachers, and some teachers made up study guides and work sheets for the visit, which was incorporated into a marine biology unit. At least 20 different MLML students served as docents for the groups. Questionnaires distributed to MLML personnel indicate a very positive response to the Visitor Days program.

Annual Spring Open House. Each spring MLML students, faculty, and staff stage an open house for the general public. This year visitors observed (and at times took part in) displays of live marine animals; demonstrations of lab equipment (such as scanning electron microscope, computers, diving and sampling equipment, and methods of seawater analysis); displays concerning current research; nature walks; boat tours (when possible); and a variety of slide shows and and movies. Simple concepts in marine ecology were vividly presented in a puppet show, which received enthusiastic response from viewers of all ages. The 1978 one-day Spring Open House was so well attended (over 5,000) and appreciated by the public that following open houses were extended over two days. This resulted in

decreased crowds and increased interpretive quality. The duration of the two-day open houses are Saturday from 10 am - 12 pm for special guests (politicians, professors and potential students from consortium campuses, governing board members, representatives of other marine labs on Monterey Bay, and families of lab personnel); 12 pm - 4 pm for the general public; and Sunday 10 am - 4 pm for the general public.

In response to numerous requests from the public, the theme of the 1980 open house was "Research at Moss Landing Marine Laboratories." Students and faculty made a special effort to present most facets of research activities at MLML, with an emphasis on in-person interpretation of displays. Over 50 students, staff, and faculty members cooperated in making the 1980 open house perhaps the most successful to date.

Feedback questionnaires from 304 people were turned in and may reflect the public response to the open house. The general success rating was 8.8 on a scale of 10 (1 designated a waste of time, 10 was a great experience), with 10 receiving the most votes. One hundred percent felt the open house was educational, and 91% felt the technical level of the exhibits and presentations was just right (5% felt the level was not technical enough; 4% felt the level was too technical). At the top of a long list of items in the *Most Liked* column were the live exhibits (aquariums, touch tanks, etc. (and MLML personnel participation (their enthusiasm, energy, and willingness to communicate). In the *Least Liked* category, only 23% responded (others left this space blank or wrote "nothing" or "liked it all"). The *Least Liked* responses referred to "crowds" (8%), and other responses were varied (none represented more than .5% of all respondants). Most people said they attended the open house for information (47%) or entertainment (39%); some (5%) indicated they were planning to attend MLML; others (4%) said they were planning to study marine science or that they wanted to help their children learn about the marine environment. Benefits to MLML include improving community relations and encouraging potential students.

Mentally Gifted Minor (MGM) marine biology workshop. In response to a request by the North Monterey County School District, MLML students presented a one-month MGM marine biology workshop in October for stu-

(Photo courtesy of Moss Landing Marine Laboratories.)

dents in grades two through eight. A local community center provided space; MLML provided materials (microscopes, aquariums, live animals, etc.) and boat time; the Sea Grant Public Education Coordinator organized and supervised the workshop. The school district MGM program provided $900, which paid ten graduate students for their time. The course consisted of a series of six lecture/lab sessions two per day for each age group) and culminated with a field trip in boats up Elkhorn Slough. The lecture/lab sessions covered oceanography, marine geology, marine plants, marine invertebrates, marine fishes, and marine birds and mammals. Each session was prepared and taught by a graduate student in that area of concentration.

Continuation high school Elkhorn Slough mini-course. This summer, a local continuation high school requested help in presenting a mini-course on the ecology of Elkhorn Slough. Approximately 15 students were given previsit materials and an assignment to study available careers in wetlands biology. Each student researched a bird that might be encountered in Elkhorn Slough, noting feeding behavior, migratory patterns, habitat preference, etc. On site, students were given a tour of MLML facilities, followed by a boat trip up the Slough to observe human influences on the Sough (now an Estuarine Sanctuary), shore birds, and fish. Two otter trawls were conducted, one in the upper Slough and one in the lower for comparison. Students enthusiastically helped each other identify "their" birds and fill out fish species lists. The instructors and students enjoyed the trip and found it educational. The students offered to do some ecological work for MLML in appreciation for the trip.

Intern program. We initiated an intern program in which interested high school students take part in field research at MLML under the supervision of an MLML scientist. So far six students have participated in benthic and salt marsh ecology projects.

Summer marine biology workshops. Approximately 40 children attended two 2-week summer marine biology workshops taught by MLML graduate students. The courses consisted of five lab sessions covering physical oceanography, biology, and ecology, and four field trips to various local marine habitats.

The Lyceum of the Monterey Peninsula provided $540 for stipends for two graduate student teachers.

Ad hoc tours of MLML. Due to lack of time, space, and funding, and problems with disruption of teaching and research, we can't fill this need completely. The Visitor Days program and the general open house alleviate some of the need, but we still get many requests from schools and other community groups as well as drop-in visitors. Groups are requested to fill out a "Need Form," which helps us to decide which groups to serve first. We average about one tour a month.

Outreach program. We respond to as many requests as possible for speakers, mainly to local schools and community groups. (Again, we use the "Need Form.") We have gone as far as Oakland and San Jose for large assemblies. Sometimes we speak to one classroom, but more often to some type of larger assembly (e.g., career day or a science fair). Presentations range from slide shows to bringing in diving equipment or a variety of live animals in a portable touch tank.

Miscellaneous. MLML also assists other organizations with their marine education programs. For example, lab personnel often use lab rooms, equipment, boats, etc., for such things as Audubon Society trips and adult school classes.

Humboldt State University

Our goal is to interpret for the public the marine environments of the Trinidad Bay area, in particular, and of northern California in general.

During the past year we have photographed local marine environments and their biotas. With the assistance of Greg Pic'l, graduate student; Mr. Don Neubacher and Dr. John Hewston of the Department of Natural Resources; and Jay Brown of the Humboldt State Instructional Media center we constructed a set of display panels on the theme "Physical and Biological Aspects of Marine Environments in the Vicinity of the Telonicher Marine Laboratory." We have acquired a Radio Shack TRS-80 microcomputer for testing the display panels' effectiveness in conveying information to the public. This computer will be used to ask visitors questions about the content of the panels and to store responses to the questions. Dr. James Cunningham, Director of the Institutional Research and Testing Center at Humboldt State, is helping us develop questions dealing with the displays.

We have given tours and audio-visual presentations for the public and for special interest groups at the Fred Telonicher Marine Laboratory. We are planning two workshops:

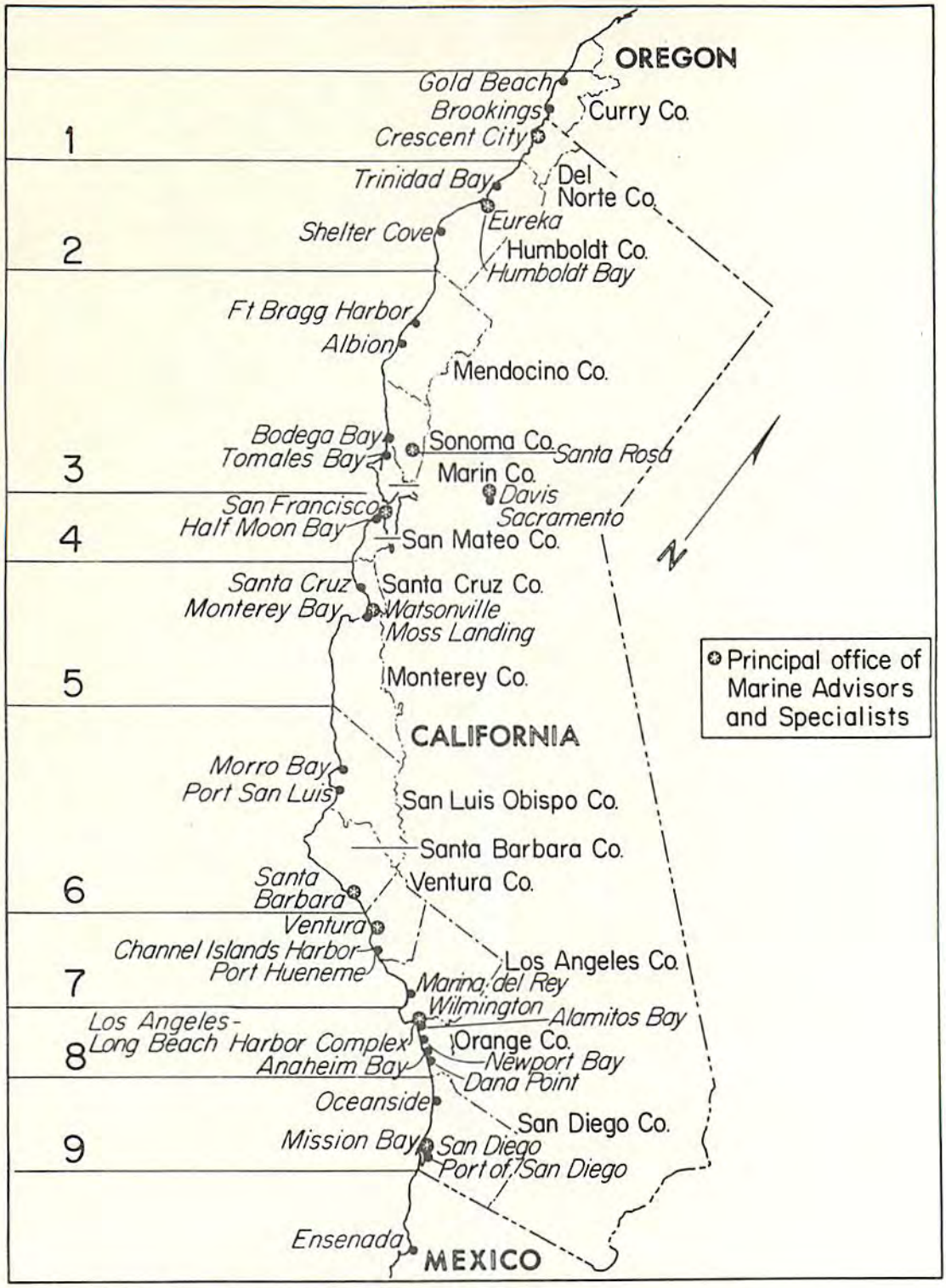
one dealing with intertidal biology for ranger-naturalists of the California Department of Parks and Recreation and the National Park Service; another on shallow tidal environments for ranger-naturalists of Channel Islands National Park.

Publications

"Living in a Watery World, Part II; Fishes, Shore Birds and Marine Mammals", for elementary teachers, is a 30-page workbook.

Cooperating Organizations

American Shellfish
Cabrillo Marine Museum
California State Parks
Castroville Community Center
ESAA, Emergency School Assistance Aid
Humboldt State University Foundation
International Shellfish Enterprises
Lyceum of the Monterey Peninsula
Mentally Gifted Minor Program
The Nature Conservancy
North Monterey County Unified School District
North Monterey County Mentally Gifted Minor Program
San Diego Department of Education
Santa Cruz City Museum
Sea Grant Marine Advisory Service



MARINE ADVISOR AREAS

Coastal Resources

Coastal Wetlands Management: Biological Criteria

UC Santa Barbara
R/CZ-33A
1978-79

Robert W. Holmes, Christopher P. Onuf, and Charles H. Peterson

The aim of our project was to make a detailed inventory of the structure and function of a culturally little-disturbed lagoon-salt marsh ecosystem to guide the future management of central and southern California coastal wetlands.

Our initial characterization of the Mugu Lagoon coastal wetland ecosystem consisted of addressing seven basic questions (see "Results" below).

With this initial characterization, we could test the effectiveness of the plan to mitigate the loss of five acres of mudflats to a proposed naval construction. The opportunity was especially valuable because the area lost was a part of the lagoon most heavily used by shorebirds, and also the proposal to greatly increase tidal exchange is probably the most commonly prescribed measure to restore degraded coastal wetlands in this region. However, the outcomes of such modifications have not been critically evaluated so far.

Another event with major repercussions for coastal wetlands management was the extraordinarily wet winter of 1978, the second wettest in 111 years. The runoff from coastal watersheds brought with it vast quantities of silt and mud and other debris. The deposition of this material, either alone or in combination with short-term reduction of salinity, caused massive mortalities of a wide variety of wetland organisms, and major changes in bottom types. Since planners and scientists alike are nearly unanimous in regarding siltation as the paramount threat to the natural resource values of coastal wetlands in this region, we resumed our periodic sampling of all important groups of organisms in key areas of the lagoon to ascertain whether this catastrophic siltation would be a transient perturbation or whether it would cause long-lasting or irreversible changes.

Results

1. Are southern California lagoons and estuaries essentially autotrophic, or do they depend upon significant introductions of allochthonous organic materials to maintain their productivity? Our analyses of the fluxes of particulate organic matter entering and leaving the lagoon have revealed a complex relationship between stage within a tidal cycle, amplitude of the tide, whether it has been preceded by a higher or lower tide, meteorological conditions, and season. Although the complexities preclude an explicit budget, the absence of a persistent net difference between inward and outward fluxes argues against a dependence on allochthonous sources of organic matter; however, some important size transformations may occur. In storms there appears to be a large net influx of large particulate organic matter (tree trunks, root masses of reeds, rushes and grasses). On subsequent spring tides this material is redistributed, some being exported, and an undetermined but large amount being deposited at the wrack line. Intermediate-sized material, especially the just-dead reproductive portions of marsh plants, may accumulate temporarily in the wrack in late summer and early autumn, but generally is exported from the lagoon on the ebbing portion of spring tides. Thus, net exchange is not indicated, but neither is independence or isolation from contiguous water.

2. Do these systems export significant amounts of organic matter--dead or living (eggs, larvae, juveniles of invertebrates or vertebrates)--into the adjacent marine environment? If so, are the species recreationally or commercially important? As mentioned above, there is no indication of appreciable net export of organic matter. Most species of fish are present in the lagoon only during the warm months. All species are represented at least partly by young individuals that grow while they reside in the lagoon (except for the viviparous shovelnose guitarfish *Rhinobatos productus*, almost all of which are pregnant females in which most gestation occurs while they are in the lagoon). In both cases the lagoon can be legitimately regarded as a nursery ground. Clearly these fishes are important in the lagoonal ecosystem, because they are abundant and actively foraging for half of the year. However, it is less likely that this importance extends to coastal fish stocks as a whole. California halibut (*Paralichthys californicus)* was the only commercially or recreationally important species that was common in our catches, and it accounted for only 3% of the total (table 1).

3. Are these areas important and perhaps unique habitats for resident and migratory birds? Most compilations of bird use of coastal

wetlands habitats do not assess the relative importance of different habitats within a region for supporting a species or group of species, nor the importance of similar habitats in different regions. With the exception of a few salt-marsh dependent species, almost all of the water-related birds in central and southern California coastal wetlands also occur in and may prefer other habitats: primarily ocean beaches and freshwater marshes and ponds. Nevertheless, it is our opinion, based in part on unavoidably subjective impressions of density of birds and intensity of use, that water-related birds are heavily dependent on these habitats in the region.

Sea Grant Trainee Millicent Quammen conducted a series of manipulative experiments to clarify the interactions of shorebirds with their infaunal prey. Her exclosure treatments in muddy areas of Mugu Lagoon and Upper Newport Bay (150 km southeast) revealed an unexpected subtlety in the impact of shorebird predation on infaunal organisms (mainly polychaete worms). At Upper Newport Bay the outcome of the experiments was straightforward. In the summer, when birds were absent, polychaete numbers were high inside and outside exclosures. During the fall migration and over winter, when shorebirds were abundant and actively feeding, polychaete numbers decreased appreciably outside exclosures but remained significantly higher in the areas from which birds were excluded (figure 1a). At Mugu Lagoon, the seasonal pattern of polychaete abundances was drastically different from Upper Newport Bay outside the exclosures (in fact almost precisely the mirror image). Also there was no discernible effect of the exclosure treatment (figure 1b).

Although the study areas were selected for their superficial resemblance, the mud at Mugu Lagoon incorporated an admixture of sand. Perhaps because of this difference in substrate, the crab *Pachygrapsus crassipes* is seasonally very abundant and active in the study area at Mugu Lagoon but entirely absent from the study site in Upper Newport Bay. At Mugu Lagoon bigger shorebirds, especially willets, were more important, and little shorebirds (sandpipers, dowitchers, and dunlin) were much less important than at Upper Newport Bay. Currently we are experimenting to determine whether substrate differences alone are responsible for the differences between sites or whether the seasonal patterns of worm abundance are governed by predation at Mugu Lagoon as well, but with the interjection of another trophic level. We are investigating the hypothesis that at Mugu Lagoon as well as at Upper Newport Bay shorebird predation governs the pattern of seasonal abundance of polychaetes, but the effect is reversed by an intermediate target of the birds' predation: the crabs crop the polychaetes to low levels during the summer when birds are absent, but abandon the exposed open mud flats, thereby allowing polychaetes to increase, when willets are present. Regardless of whether the population dynamics of the infauna are governed by substrate differences alone or in conjunction with shorebird predation, it is obvious that these subtle interactions will have to be addressed in effective management programs.

Up to now, exclosure experiments on sand flats have, at best, only suggested the interactions of shorebirds with their prey. The problems of introducing a stationary structure into flowing water on an easily suspended substrate have been a major obstacle. The resulting alteration of currents, resculpturing of bottom configuration, and alteration of substrate texture aggravated by interception of debris often compromises the validity of an outcome. This year we had good success with a large float-up exclosure, because when the water velocity was high enough to disturb the substrate in the vicinity of a physical obstruction, the exclosure was floating so far above the bottom that it was not obstructive. Furthermore, when floating debris encountered the frame of the exclosure, it either slid off to the side or under the smooth surface of the plastic tubing. Consequently, we ascertained that there were no detectable changes under, compared to outside, the exclosure in number of bivalves, substrate granulometry, or bottom configuration when birds were absent from the area. When birds were present, the density of bivalves outside declined to less than one-half the density inside the exclosures. The experiment must be repeated, but we now seem able to directly assess the interaction of shorebird feeding and infaunal food supply on sand flats as well as in muddy areas.

4. How is the total organic primary production partitioned among the aquatic angiosperms (eel grass, *Ruppia maritima*), the high marsh flora (e.g., *Salicornia*, etc.), and the algal flora? Because of the mild climate and apparent year-round growth of the evergreen perennials that dominate southern California salt marshes, we reasoned that standing crop or change in standing crop would not adequately measure productivity. Consequently, Onuf performed a tagging study and conducted a monthly harvest to esti-

Table 1
The Total Catch of Fish at Mugu Lagoon in 1977, 1978, 1979 and 1980 for All Months That All the Same Stations Were Sampled in Each Year (March to October)

		Number Caught				Direction of Change				
		1977	1978	1979	1980	1977-78	1978-79	1979-80	1977-79	1977-80
Cymatogaster aggregatus	Shiner surfperch	2807	2603	99	18	-	-	-	-	-
Atherinops affinis	Topsmelt	2526	1496	2582	1857	-	+	-	+	-
Leptocottus armatus	Staghorn sculpin	527	701	2635	573	+	+	-	+	+
Fundulus parvipinnis	California killifish	118	120	153	329	+	+	+	+	+
Paralichthys californicus	California halibut	227	168	116	338	-	-	+	-	+
Hypsopsetta guttulata	Diamond turbot	138	57	118	160	-	+	+	-	+
Geneonemus lineatus	White croaker	193			1	-		+	-	-
Syngnathus leptorhynchus	Bay pipefish	70	44	5	5	-	-	0	-	-
Gillichthys mirabilis	Longjaw mudsucker	86	105	28	10	+	-	-	-	-
Symphorus atricaudus	California tonguefish	29	8	92	25	-	+	-	+	-
Engraulis mordax	Northern anchovy	9	3	3		-	0	-	-	-
Paralabrax nebulifer	Barred sandbass	1				-			-	-
Mustelus californicus	Grey smoothhound	8	21	22	12	+	+	-	+	+
Hypsoblennius gentilis	Bay blenny	14	4		4	-	-	+	-	-
Seriphus politus	Queenfish	19		2	210	-	+	+	-	+
Heterostrichus rostratus	Giant kelpfish	13				-			-	-
Sebastes atrovirens	Kelp rockfish	14				-			-	-
Paralabrax clathratus	Kelp bass	4		19	1	-	+	-	+	-
Citharichthys stigmaeus	Speckled sanddab	11		58	5	-	+	-	+	-
Sebastes auriculatus	Brown rockfish	10				-			-	-
Quietula y-cauda	Shadow goby	6	1			-	-		-	-
Rhinobatos productus	Shovelnose guitarfish	7	2	5	3	-	+	-	-	-
Girella nigricans	Opaleye	6		3		-	+	-	-	-
Embiotoca jacksoni	Black surfperch	4				-			-	-
Albula vulpes	Bonefish	5				-			-	-
Sebastes elongatus	Striped rockfish	4				-			-	-

Amphisticus argenteus	Barred surfperch	3	1			-	-		-	-
Clupea harengus	Pacific herring	1				-			-	-
Urolophus halleri	Round stingray	2			7	-		+	-	+
	Kelpfish II	1				-			-	-
	Kelpfish III	1				-			-	-
Triakis semifasciata	Leopard shark	1	1	1	4	0	0	+	0	+
	Rockfish III	1				-			-	-
Sebastes serranoides	Olive rockfish	1				-			-	-
Platichthys stellatus	Starry flounder			8	4	-	+	-	+	+
Pleuronichthy ritteri	Spotted turbot									
Peprilus simillimus	Pacific butterfish			1			+	-	+	
TOTAL	Number of individuals	6866	5335	5950	3566	+ = 4	13	6	9	9
	Number of species	34	16	19	19	0 = 1	2	1	1	
						- = 29	7	15	26	26

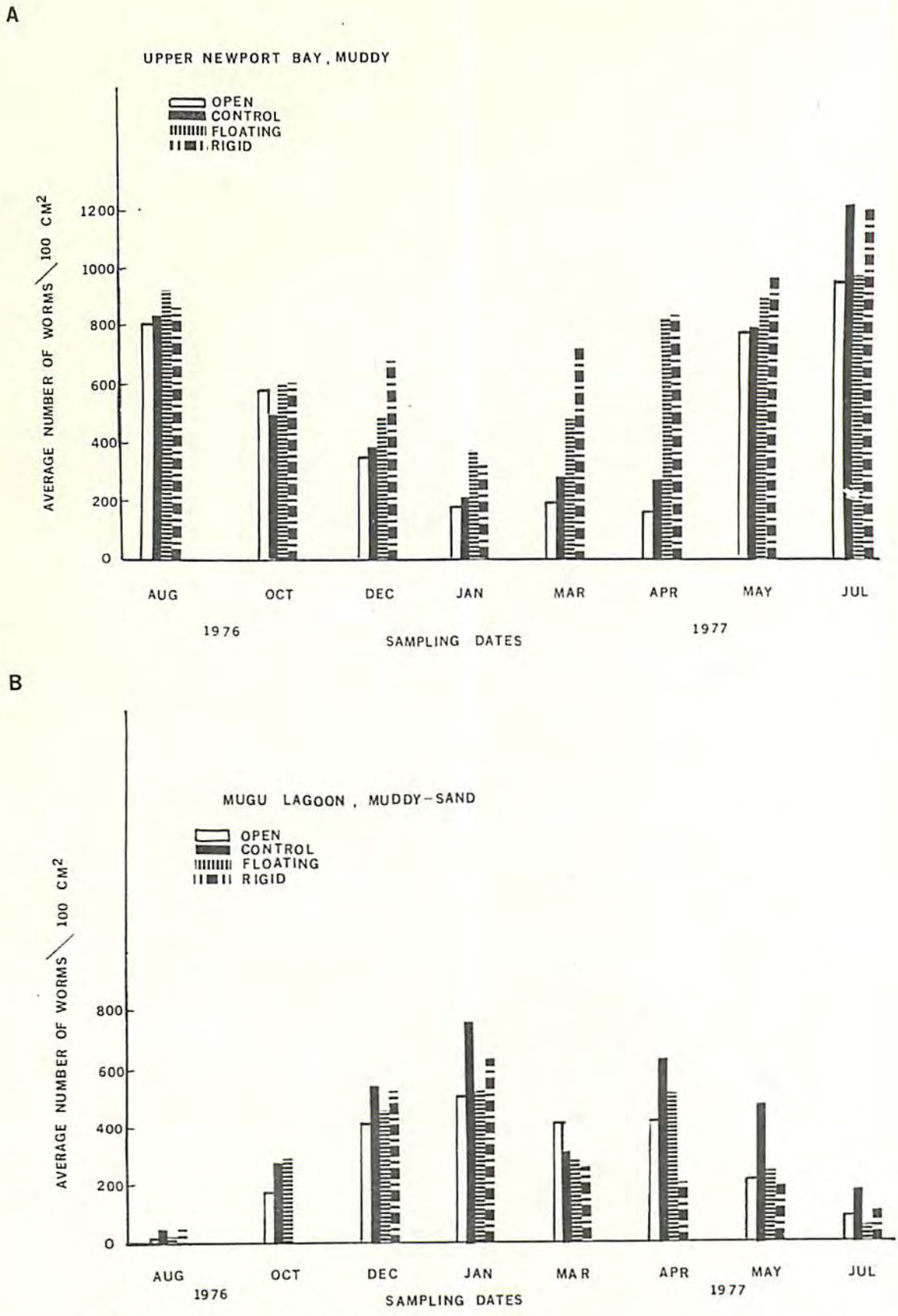


Figure 1. The changes in the numbers of polychaete and toligochaete worms in exclosures as a result of shorebird and fish predation.

mate and compare production by different techniques (figure 2).

Considering all species, the productivity of the salt marsh at Mugu Lagoon is low compared to other regions. This result generally agrees with the findings of Zedler in our companion project at Tijuana Estuary (R/CZ-33C). Also in agreement with Zedler's work, we find that the productivity of the epibenthic microflora is comparable to or higher than that of other regions. Phytoplankton productivity is much less than epibenthic productivity. Our preliminary estimates for submerged aquatic macrophytes suggest that the algal components (mainly *Enteromorpha* this year) are comparable to, and may exceed the levels of epibenthic microflora.

Although net primary production as determined by dissolved oxygen techniques for algae is not directly comparable to the estimates of salt marsh net primary production by tagging or harvest techniques (because some of the former is excreted as dissolved organic matter while all of the latter is accumulation measured as dry organic matter), it nevertheless seems likely that an area of the continuously submerged part of the lagoon will be appreciably more productive than an equivalent area of salt marsh. Since much of the dead material from the salt marsh can raft out as flotsam without ever being available for the consumers of the lagoon, it is likely that the productivity of the submergent plants will be much more important for supporting the lagoonal fauna.

5. What is the fate of organic matter produced, especially relating to the broad food web structure in this ecosystem? All of our studies of birds (see 3. above) beyond the routine censuses deal with the structure of the lagoonal food web. The exclosure experiments on the mud flats were designed to separate out the effects of fish feeding from bird feeding on infauna. In addition, Quammen has analyzed the gut contents of up to 40 individuals per month of all the important species of fish that we caught in the lagoon. Interestingly enough, it appears that not only do fish and birds exploit the resources of the lagoon differently in time (fish during the warmer months, birds during the colder months), but also by kinds of prey (fish concentrate on epifaunal and planktonic invertebrates; birds concentrate on infauna and fish; however, both sharks and willets love crabs). In addition, Peterson has been investigating food web interactions both within and between trophic levels.

6. What are the effects of public access and harvest of lagoonal biota upon the ecosystem?

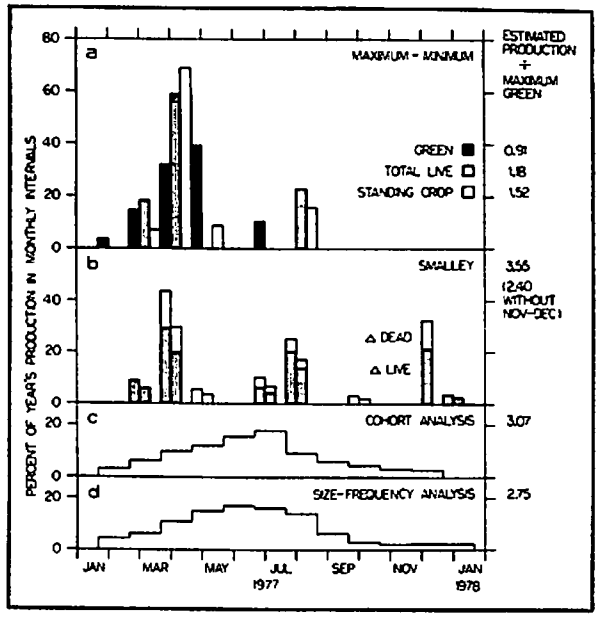


Figure 2. The distribution of production by *Salicornia virginica* over a year (left) and the relationship of total production for the year to the maximum biomass of green growing tips present at one time (right margin) as estimated by different methods. In b., the Smalley method, each pair of bars is the estimate with (right) and without (left) the November-December data.

Peterson's experimental analyses of the life histories of two species of clams once harvested in California bays and lagoons -- common littleneck *Protothaca staminea* and wavy chione *Chione undatella* -- yield opposite conclusions about their suitability for exploitation, even though they are morphologically, taxonomically, and ecologically alike and often occur at similar densities.

At Mugu Lagoon *Chione* is characterized by low rates of mortality and recruitment. Furthermore, it appears to show no compensatory response in its reproductive success either among local plots of varying density or among years when adult clam density over the whole lagoon differs. As a result, *Chione* has little value as a sustained-yield resource when compared to *Protothaca*, which (1) recruits predictably and heavily each year, and (2) shows some adverse density dependence in both adult survivorship and juvenile recruitment. Such life history characteristics are extremely important to the value of any natural biological resource. Neither species was adversely affected in growth or survivorship when removed from and replaced in the substrate twice, compared to once, over the course of a summer, suggesting that the incidental disturbance to these clams during harvest of neighboring ones will not be deleterious in a properly managed program. However, this appears not to be the case for the

ghost shrimp *Callianassa californica* in sandy areas. In another series of experiments comparing untouched areas to adjacent areas that had been trampled or shoveled but from which nothing was removed, overall abundance of macrofauna was reduced by one quarter, but *Callianassa* was the only common species that declined appreciably in proportion to the total.

7. How rapidly does this type of ecosystem recover from disturbance? We have devoted a major part of the last year of this grant and will devote much of our next grant to analyzing response to disturbance, because in the case of severe siltation we must entertain the possibility that the changes are irreversible. (For instance, the infilling with mud may have so reduced the lagoon's tidal prism that tidal currents will never again be fast enough to carry away the mud or deposit new sand to restore the previous proportions of different bottom types.) In the case of increasing tidal flushing as a mitigating procedure, it is of course by design that the system should achieve a distinctly different and, by at least some criteria, a better steady state.

Most of the samples collected since the heavy rains have not been analyzed; therefore the results available at this time are for samples that could not be stored or did not require lab processing. For marsh plants the biomass of green growing tips of *Salicornia* harvested at the time of maximum standing crop was 5, 82, 102, and 121% greater the year after the heavy rains than the year before. An additional four areas were sampled since the big rains. The biomass of green growing tips of *Salicornia* declined on seven of the eight areas between samplings. The overall decline amounted to 44%. For the four areas sampled all three years, this decline almost exactly erased the increase of the preceding year. The stimulation of plant growth during the first growing season after the rains probably resulted from the fertilizing effect of the layer of fresh sediment, with perhaps an added benefit that the storm-freshened waters briefly covering the marsh leached salts from the substrate. It remains to be seen whether the return to pre-1978 levels in the next year indicates a long-term steady state or whether the decline will continue.

Comparing our catches of fish for the interval from March to October before and after the heavy rains of early 1978, it is apparent that the number of declining species greatly exceeded the number that increased (table 1). The species that increased were generally the ones that we found to be hardiest as we processed the catches. Their tolerance of the elevated temperatures, high turbidity, and reduced oxygen of our holding buckets presumably indicates their adaptations to the same stresses in the shallow waters of coastal sloughs. The species that diminished or disappeared were associated with the extensive eelgrass beds of the lagoon prior to the rains. Large portions of the bed were buried outright by up to 15 cm of very fine sediments. Almost all of the remainder dwindled away during the next year. The overall impression is that the consequences of the siltation are highly persistent.

In our study of the effects on bird use of opening up the mouth of the western arm of Mugu Lagoon, we expected an appreciable lag between the alteration of tidal regime and changes in the activities of water-related birds, because changes in the boundary between salt marsh and open flats, substrate composition, and kinds and abundances of aquatic plants and invertebrates would have to occur first. Instead, shifts in bird use are discernible after only nine months by comparing the western arm and the

Table 2

A. Mean number of birds of different kinds seen per census at Mugu Lagoon.

	western arm		eastern arm	
	post-opening 1979	pre-opening 1978	1979	1978
Shorebirds				
Probing feeders	112	94	101	180
Surface feeders	524	245	130	119
Fish eaters	23	47	21	36
Mollusc eaters	106	322	66	52
Dabblers	545	879	66	46
Gulls	27	9	16	12

B. Percent change in mean abundance between years in altered (western arm) and unaltered (eastern arm) parts of the lagoon. The means are based on 17 censuses in 1978 and 18 in 1979.

	western arm 1979 vs 1978	eastern arm 1979 vs 1978	possible effect of increased tidal exchange in western arm
Shorebirds			
Probing feeders	+ 19%	- 44%	Increase
Surface feeders	+ 114%	+ 9%	Increase
Fish eaters	- 51%	- 42%	No change
Mollusc eaters	- 67%	+ 27%	Decrease
Dabblers	- 38%	+ 43%	Decrease
Gulls	+ 200%	+ 33%	?(small sample size)

unaltered eastern arm before and after the opening of the western arm (table 2). The increase in shorebird use of western compared to eastern arm after the alteration suggests that the proposed mitigation was successful. On the other hand, the numbers of dabblers and mollusc-feeders (mainly coots and ducks) have decreased. The shift toward shorebirds and away from waterfowl is likely to persist, because the more open mouth causes the whole arm to drain much more completely than it used to, reducing the area of permanent water cover and increasing the area of periodically exposed muds. Obviously this trade-off has to be recognized in evaluating the mitigation procedure.

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Cooperating Organizations

California Coastal Commission

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

Coastal Wetlands Management--Effects of Disturbance on Estuarine Functioning

San Diego State
R/CZ-33C
1978-79

Joy B. Zedler and David A. Mauriello

In order to manage coastal wetlands wisely, it is essential to be able to predict how various disturbances will affect their structure and functioning. This project has studied southern California wetlands, first of all in their relatively undisturbed state, and then through comparisons and controlled experiments, under the effects of various alterations. Prior to this research, there had been no studies of estuarine processes in this region. Management has relied upon the extensive data base for Atlantic coastal wetlands for justifications of wetland values and predictions concerning cause-effect relationships. This project has made it clear that extrapolations from eastern wetlands will not hold in San Diego County.

San Diego County wetlands are rare and endangered ecosystems. The fact is emphasized by comparison with salt marshes of the Georgia coastline, an area of similar latitude and latitudinal extent. For every acre of salt marsh in San Diego there are approximately 100 in Georgia. Rather than forming continuous cover along the coast, California wetlands are small and separate. On the average, they occur at ten-mile intervals and comprise about 230 acres (excluding San Francisco Bay wetlands). The small size of California wetlands results from steep coastal topography, which means that watershed areas are small and river floodplains are narrow. In southern California, low rainfall compounds the effects of small watersheds, so that freshwater input is both rare and minimal. Although comparative data are not available for California's 110 wetlands, it is likely that those in the arid southern portion of the state function differently from those with greater freshwater input. For this reason, extrapolation from southern to northern California systems may be as inappropriate as extrapolation from eastern to western United States wetlands.

Functioning of Arid Region Wetlands: A Conceptual Model

Like other tidal wetlands in arid regions, Tijuana Estuary (TJE) is predominantly influenced by seawater and not runoff. Freshwater can dilute the channels during winters of heavy rainfall, but usually channel salinity approximates that of the adjacent ocean (34 ppt). The degree of tidal flushing is related to a number of factors, including channel morphometry, watershed size, and historical changes in sedimentation and scouring. The Tijuana Estuary is usually open to tidal flushing, perhaps because roadbeds do not significantly reduce its tidal prism.

Both the salinity of the tidal water and the inundation levels have a major effect on wetland structure and functioning. The intertidal areas of the Tijuana Estuary slope toward the channels and provide a gradient of salinity and inundation frequency that correlates with elevation. Because of frequently hypersaline soils and sloping topography, most of the intertidal marsh is dominated by salt tolerant "high marsh" species (*Salicornia subterminalis*, *S. virginica*, *Suaeda californica*, *Monanthochloe littoralis*, *Frankenia grandifolia*, *Triglochin concinnum*, *Batis maritima*, *Jaumea carnosa*, *Salicornia bigelovii*). Only the narrow band of low elevations near channels is dominated by the cordgrass *Spartina foliosa*. At all elevations, the vegetation has a rather open canopy, and light penetrates to the soil surface, allowing the development of thick, highly productive algal mats. These conditions contrast sharply with coastal wetlands in humid environments. The marshes of Georgia are largely "low marsh" environments dominated by the cordgrass *Spartina alterniflora*. The grass is tall and dense, especially near creeks, and light penetration to the soil is apparently insufficient to allow growth of dense algal mats. Only a thin diatom film occurs in these marshes.

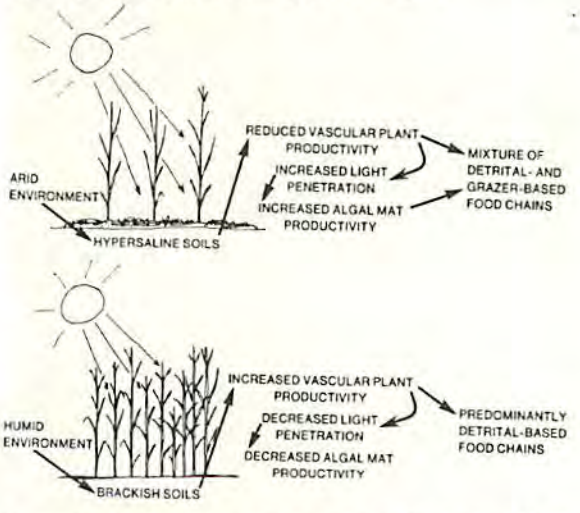

Figure 1. Conceptual model comparing functioning of coastal wetlands in arid and humid regions of similar latitude.

The contrasts between arid and humid region wetlands have led to a general model of salt marsh functioning, emphasizing the effects of salinity upon the base of the food chain (figure 1).

This model was verified for southern California wetlands by events at Los Peñasquitos Lagoon, which became brackish when freshwater accumulated behind a sand bar. Vascular plant productivity increased substantially and algal mats were absent. However, the ultimate effect of having a mixture of vascular plants and algal producers upon the higher trophic levels is still speculative. If, as suspected, the grazer-based food chain is more important in hypersaline marshes, then more of the primary productivity would be funneled to higher trophic levels. In other words, a kilogram of digestible algae would support a larger animal biomass if consumed directly by an invertebrate herbivore than would a kilogram of fibrous cordgrass, which would first be processed by decomposers before becoming usable by invertebrates. Feeding experiments have demonstrated that salt marsh vascular plants are of poor food quality for mussels, which filter particulate matter out of the water column. Further studies, tracing plant foods through estuarine food chains, are needed to test this part of the model.

Tidal wetlands are dynamic ecosystems, with water and materials moving from the ocean to higher intertidal areas and back again. Study of these processes at TJE has shown that materials are being shifted from one location to another, but that the direction and magnitudes differ through the year. The net annual effect (figure 2) is a flux of organic carbon from the marsh to its adjacent tidal creeks (almost entirely in the dissolved form), a probable mineralization of organic matter in the creeks, followed by a flux of ammonia from the creeks to the marsh. Movements of materials from the channels to the ocean also occur and, in general, there is an export of organic carbon and inorganic nitrogen except during early fall, when spring tides are especially high but freshwater runoff does not occur. Major export occurs during winter with high tides and freshwater runoff. Tidal flushing, therefore, is essential for maintenance of these fluxes. Our comparisons with LPL have shown that without tidal flow, materials accumulate in the wetland, exchanges are inhibited, and very different conditions exist (figure 2).

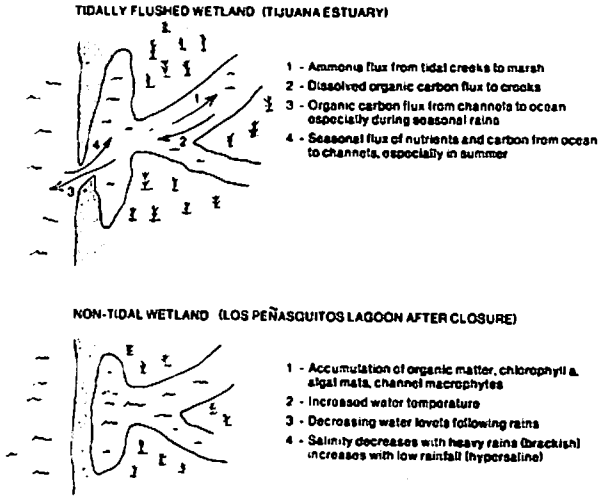

Figure 2. Movements of materials in tidally circulated wetlands and closed lagoons.

Effects of Disturbance on Estuarine Functioning

In order to predict the consequences of various environmental modifications on wetlands, it is necessary to understand the effects of disturbances. Knowing the relationships between environmental changes and the wetland organisms allows one to assess both planned and unintentional alterations. Because wetlands are potential sinks for materials in the watershed, distant activity may ultimately affect salt marshes or estuarine channels.

Disturbance effects can be identified in various ways--by comparing disturbed and undisturbed wetlands, by comparing conditions before and after disturbance, and by performing controlled experiments. There are problems in interpreting results from each approach, however. No two wetlands are identical, and differences between systems may be due to more than their disturbance histories. Likewise, differences before and after a disturbance may relate to factors other than that event. Finally, experiments are rarely able to duplicate field conditions, and it is difficult to extrapolate from the experiment to the total wetland. In this study, a combination of approaches has been used; together the results indicate that wetland ecosystems are sensitive to disturbances.

Effects of various types of disturbances were assessed on the base of the salt marsh food chains, namely vascular plants and algae. In general, the two plant types show distinct responses. Algae respond more quickly to environmental changes and recover more rapidly from disturbance because of their small size, rapid growth rates, and broad dispersal capabilities. However, because of their general inconspicuousness and rapid recovery, it is harder to see the effects of disturbance without continuously monitoring some property such as

algal mat photosynthesis. Vascular plants, which are larger, will be more obviously damaged by disturbances such as trampling, and recovery will probably take several growing seasons. Conditions detrimental to vascular plants may be advantageous for algae, because of the effect of overstory shading on algal mat productivity. In both vascular plants and algae, the communities respond first by changing their functional characteristics (e.g. increasing or decreasing productivity). Changes in structural attributes (species composition and abundance) are slower. For vascular plants, this is due to poor dispersal and reliance upon vegetative reproduction; whereas for algae, it is because of their tolerances for a broad range of environmental conditions.

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Cooperating Organizations

California Department of Parks and Recreation
Scripps Institution of Oceanography (Dr. O. Holm-Hansen)
U. S. Fish and Wildlife Service

Wetlands Management in Coastal Zone Planning: A Prototype Framework for Relating Natural Science and Land-Use Planning

UC Berkeley/Moss Landing
R/CZ-45
1978-80

Thomas G. Dickert, James Nybakken, Gregor M. Cailliet, Michael S. Foster, G. Victor Morejohn, and Gary Page

Elkhorn Slough Watershed Study

Protection of coastal resources, such as wetlands, is partially dependent on land-use activities that occur within the upstream watersheds. The purpose of this research has been to investigate the aspects of urbanization and agricultural development that may affect the estuarine environment; we made a case study of Elkhorn Slough, located in northern Monterey County, California. The work has focused on the hydrologic processes of streamflow and sediment movement, which are perhaps the single most significant processes linking uplands to wetlands, and are processes that can be positively or negatively influenced by a land-use planning program.

The major focus of the research has been to develop a model land-use planning system to relate the type and intensity of proposed land use within the watershed to the capacity of the wetland. The planning system includes an erosion-susceptibility map for the watershed and land-development targets for each subwatershed (See figure 1). If development is allocated to subwatersheds according to the suggested target level of allowed site disturbance, and is located on lands in the lower erosion-susceptibility classes, then the rate of change in the wetland environment attributable to sedimentation will not accelerate beyond current rates. Land-use targets for each subwatershed are portrayed in figure 2.

The intent of the erosion-susceptibility map and disturbance targets is to account for the cumulative effect of development within the entire watershed of the estuarine system. It will then be possible to review, project by project, the contribution of a single development to the cumulative effect on the entire watershed system.

Research to support the analytical planning system has been conducted in four areas:

1. Hydrologic processes related to runoff in streams tributary to Elkhorn Slough
2. Erosional and depositional processes occurring on various land uses in the upland and wetland portions of the watershed
3. Detailed measurements of land-use changes occurring over fifty years (1931 to 1980) in the uplands and wetlands of the watershed, as measured from a time series of aerial photographs.
4. Measurements of site disturbance (impervious surface and bare soil) associated with a range of types and intensities of land use.

Hydrologic analysis. Work was conducted on the rainfall, runoff, and sediment transport relationships within the Elkhorn Slough watershed. Only limited rainfall data and no runoff data were previously available for the study area. Daily, monthly, and annual rainfall values for the watershed were calculated by applying the Thiessen method to existing regional rainfall records.

We analyzed stream discharge using three techniques: flood frequency analysis (frequency

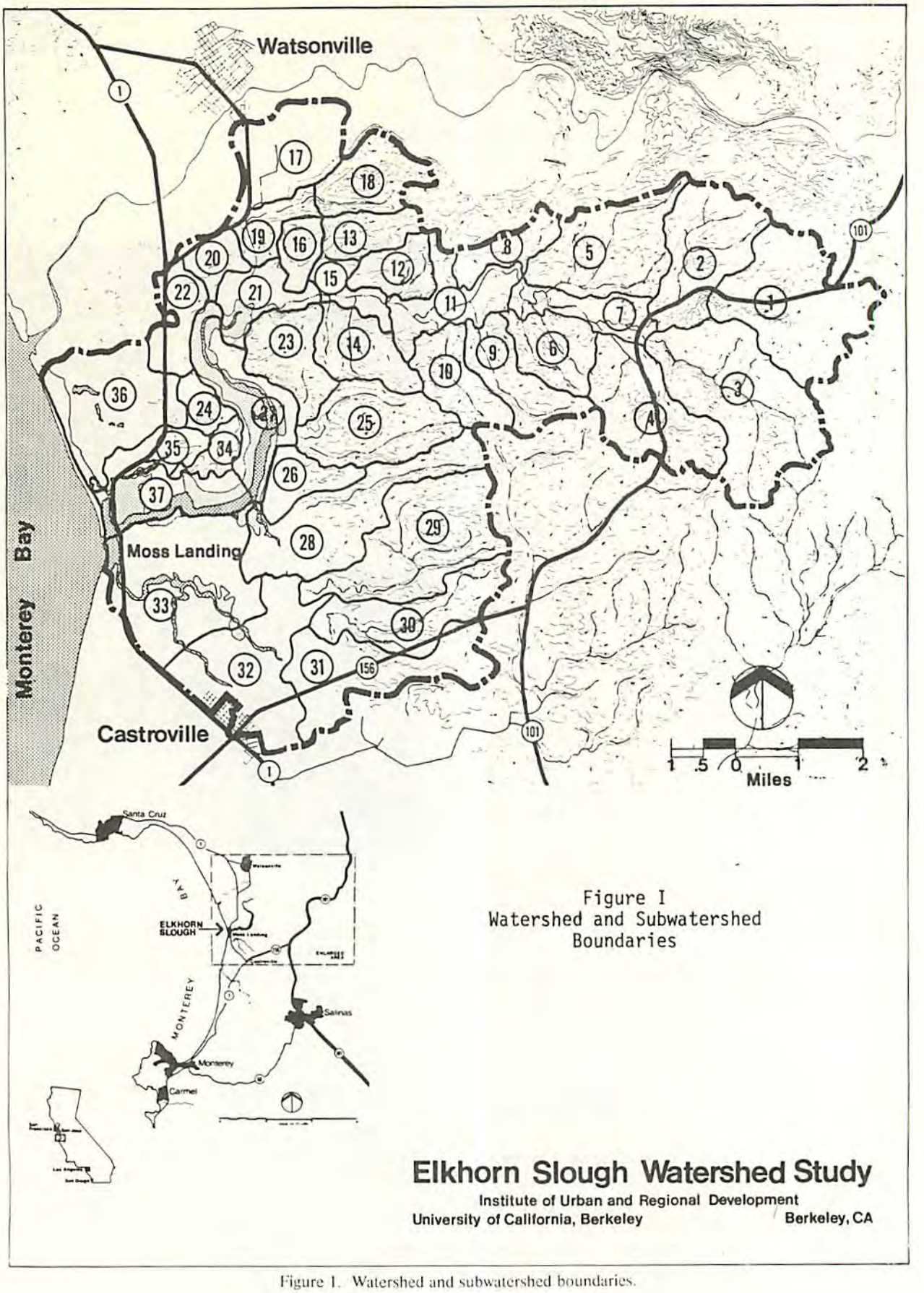

Figure I
Watershed and Subwatershed Boundaries

Figure 1. Watershed and subwatershed boundaries.

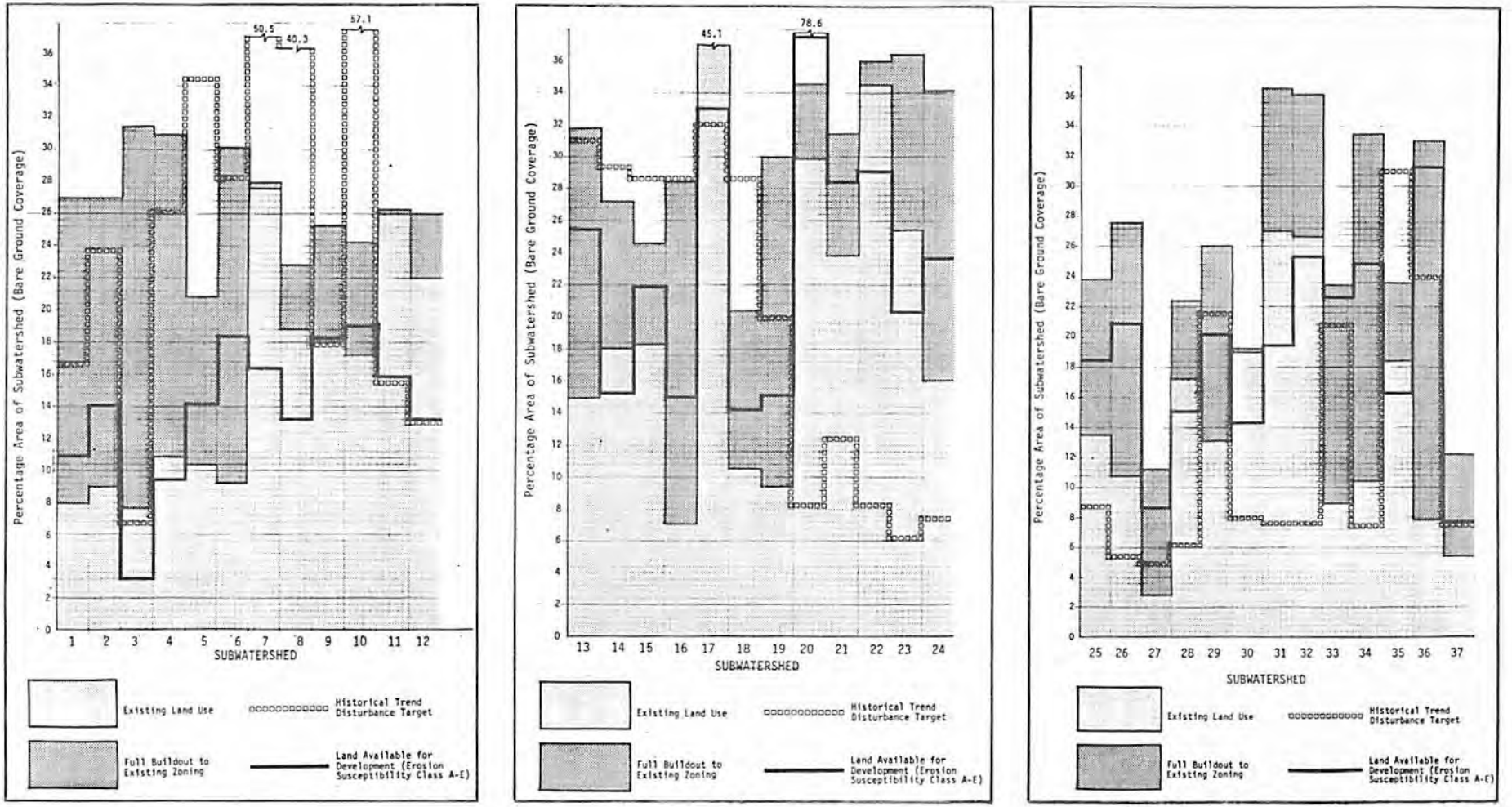

Figure 2. Land-use targets for each subwatershed.

analysis of recorded data, Rational Method, Rantz Regional Frequency Method, and the Rantz Modified Synthetic Unit Hydrograph); hydrograph simulation (unit hydrograph, runoff coefficient, and SCS Curve Number method); and field measurements during winter storms. The majority of storms measured in the field had a high frequency and thus provide a measure of stream discharge from existing levels of development. The hydrographs provide important baseline information on runoff from which the hydrologic impacts of proposed developments within the watershed can be determined.

We made limited investigations of sediment transport for the major tributary stream, Carneros Creek. Suspended sediment samples were taken with standard sampling technique, and bedload transport samples made with a Helly-Smith sampler. Bed transport was also documented by bedload chains. These samples provide evidence of substantial sand movement occurring with normal flows each winter along the creek bed. It is expected that this material is transported to, and in part deposited in the upper reaches of the slough.

Upland erosion and deposition. We analyzed erosion and deposition by using erosion pin transects to determine relative erosion/deposition rates. Transects were established on over thirty sites representing a range of combinations of land use, ground slope, and soil type. The erosion pin technique provides field evidence of both erosion and deposition occurring on a site over time.

Irrespective of slope, erosional and depositional activity was found to be highest on sites where natural cover had been removed and the soil disturbed. Cultivated agriculture was found to produce much more erosion and deposition than urban or naturally vegetated sites. Slope was an important factor on agricultural and urban sites, but did not appear to increase erosion on undisturbed sites.

Deposits of sand originating from downcutting stream channels are forming on the wetland flats on the west side of the slough. Deposits of sand and mud are burying localized portions of *Salicornia* habitat and altering the wetland community structure. The fans are a direct result of agricultural irrigation water being discharged into the natural stream channels draining the slope. The augmentation of natural flow has caused downcutting and bank erosion as the channel morphology adjusts to increased discharge. The size and number of these fans can be expected to increase as development intensifies adjacent to the slough.

Time series analysis. The time series analysis has established the land-use and wetland changes that have occurred within the watershed over the past fifty years. Aerial photographs of the watershed dating from 1931 to 1980 (1931, 1949, 1956, 1966, 1971, 1980) were interpreted, and the acreages of each land-use type were mapped, measured, and presented in graphic form.

The general trend in the watershed has been intensification of basically rural land uses. Whereas land parcels were largely undivided pasturelands in 1931, by 1980 the landscape had been highly dissected by roads and residential neighborhoods.

Although always agricultural, the nature of the crop types in the watershed has changed from low-intensity pasture to high-intensity strawberries, artichokes, berries, and nurseries. Commercial production of such crops requires extensive site preparation and service roads, which result in significant ground disturbance and soil exposure.

As is typical of California coastal wetlands, the wetlands of Elkhorn Slough have been drastically altered. Approximately 45% of the *Salicornia* habitat and 48% of other wet grasslands surrounding the slough have been converted to upland uses since 1931. Most of this loss is associated with diking and draining projects occurring between 1931 and 1956 (only minor wetland conversion is evident in the 1931 photographs). Since 1971 a small amount of the diked acreage has been restored to tidal action by abandonment of levees and tide gates, and these areas are now returning to a *Salicornia* community. Graphs relating the land-use changes by subwatershed since 1931 and cross-sections of slough habitat types have been developed in this analysis.

Measurement of site disturbance. We made site disturbance measures for the dominant land-use types found within the Elkhorn Slough watershed. These measures were derived by sampling impervious surface and bare soil occurring on parcels that represent land uses allowed under the present Monterey County zoning ordinance. We identified sample parcels on the 1980 color infrared photography (scale 1:12,000), and measured acreage of disturbance from the photographs. Impervious surface was measured for such areas as roofs, parking surfaces, playing courts, and paved roads. Bareground measurements included such areas as cut-and-fill slopes, soil between row crops, animal enclosures, and dirt roads. Standard statistical measures were determined for site dis-

turbance by land-use type, zoning classification, and vegetative cover.

In general, the values for mean impervious surface coverage found in the Elkhorn watershed were higher than values found in the literature. Similar comparisons for bare soil could not be made, as comparable measures could not be found.

Total site disturbance for the watershed and each subwatershed was calculated by multiplying the appropriate disturbance factor by the total acreage of that use type. This was performed both for existing land use and for the built-out land use projected in the present Monterey County zoning map.

The primary conclusions for this analysis are that the cumulative impacts of impervious surface coverage for the land uses now existing in the watershed are relatively low, and will continue to be low even under full build-out of present zoning. In contrast, the amount of bare soil exposed by present land uses is very high, and can be expected to increase as clearing for rural residential or intensive agriculture increases. On the basis of this finding, we established the land-use targets relating site disturbance to rates of land-use change.

Elkhorn Slough Infaunal Studies

The major objectives of the infaunal studies were (1) to analyze the existing infaunal data base of the slough to ascertain the types of communities present and their geographical extent, (2) to see if there were any correlations between the dominant infauna species and measured physical factors, and (3) to obtain information on the effects of increased sedimentation on selected invertebrate species.

We observed geographic patterns in the distribution of benthic invertebrates after examining data from quantitative surveys at thirty-nine stations in the slough, extending from 1974 to 1980. Of the invertebrate species that were adequately identified, three taxonomic groups dominated the samples--polychaetous annelids (103 spp.), molluscs (61 spp.) and crustaceans (76 spp.). In all three groups, increasing numbers of species were found in a gradient moving from high intertidal to subtidal areas, and from the head toward the mouth of the slough. Peak seasonal abundances generally showed the opposite trend, with densities increasing from subtidal to intertidal areas and from the mouth to the head of the slough.

Since the polychaetes made up a high proportion of the invertebrates occurring in the slough, and 100 of the 103 species identified were represented in subtidal samples, one set of summer samples taken in the channel along the length of the slough was used to analyze for a zonation pattern. Using Morisita's similarity index, coupled with a hierarchical agglomerative clustering technique, we discovered the lower slough stations to be highly similar and tightly clustered, whereas the upper slough stations formed a separate group. The separation coincided with the upper extent of a tidal prism located approximately 4.8 km up the slough. No other zonal patterns were consistently discernible, indicating the relative uniformity of broad areas of the slough with respect to infaunal associations.

Pearson product moment correlations analysis was used to attempt to sort out relationships or consistent patterns between dominant species and measured physical factors (temperature, salinity, sediments, dissolved oxygen and nutrients) as well as among the species themselves. Significant negative correlations ($P < .05$) were found between the polychaete *Armandia brevis* and temperature and salinity, between the polychaete *Capitella capitata* and sediment grain size, and between the polychaetes *Ctenodrilus serratus* and the cumacean *Cumella vulgarus* and suspended sediments. We obtained significant positive correlations ($P < .05$) for the amphipods of the genus *Corophium* and salinity and the polychaete *Exogone lourei* with sediment. Considering the numbers of species and the factors analyzed, this is a very small number of significant correlations, and reveals no consistent trends for any single physical factor. That in turn suggests again the relative uniformity of the Elkhorn Slough infaunal system.

We used two methods to investigate the effects of increased sedimentation on selected infaunal invertebrates. First we subjected natural communities in the upper slough to catastrophic burial by enclosing them within open cylinders and depositing varying amounts of sediment on top. The results of these experiments indicated that burial with 5 cm or less had little effect on the organisms. However, with increasing burial depths, the ability of the animals to burrow upward was reduced, and mortality was greatly increased. Few organisms could escape from burials of 15 cm. The exception was the amphipod *Eogammarus confervicolus*, which successfully escaped from all burial depths.

For our second method of evaluating the effects of increased sedimentation, we con-

structed special sediment traps. These traps slowed the water movement, leading to an increased rate of sedimentation in the trap. Measurement of changes in sediment depth, both inside and outside these traps, was done biweekly. Results indicated that sedimentation and erosion varied markedly within a short time, both within the traps and outside, and were occasionally very high (figure 3). These

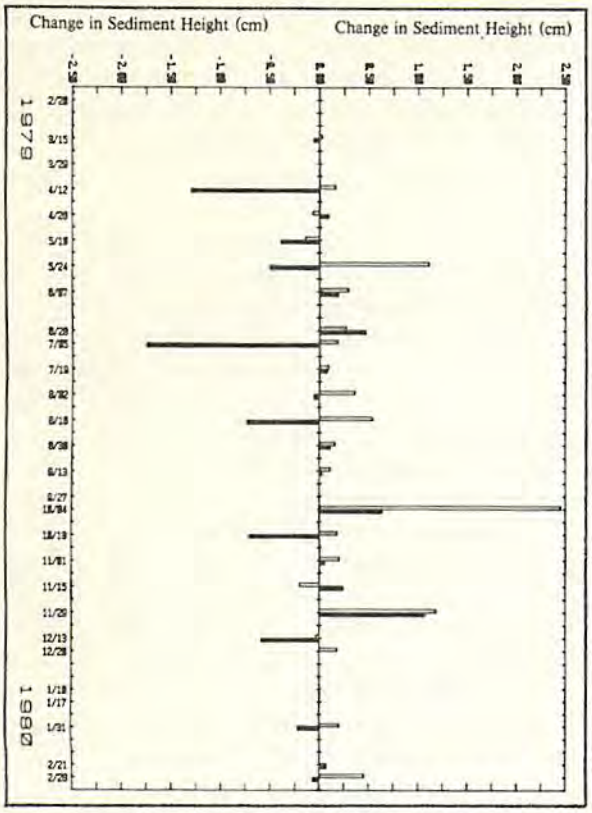

Figure 3. Changes in sediment height at locations inside (white) and outside (black) of the sediment traps. Changes are the measured differences between the listed date and the immediately preceding date.

results suggest that long-term sedimentation rates based on a few infrequent measurements were not adequate to describe the sedimentary environment of short-lived infaunal organisms, especially when the sedimentation change in a two-week interval can greatly exceed the annual rate (table 1). These results further suggest that all slough infaunal invertebrates must be capable of burrowing daily through at least a few centimeters of sediment. This correlates well with the results of our burial experiments, where most organisms could burrow through 5 cm of deposited sediment.

The effects of increased sedimentation on the abundance, reproduction, and life history of the two dominant polychaetes, *Streblospio benedicti* and *Ctenodrilus serratus*, as documented by comparing populations within our traps (high sedimentation) with those immediately outside

Table 1
The Highest Sedimentation Rates and Interval of Occurrence

Location	Time Interval	Sediment Height Increase (cm)
Trap	November 15-29	16.5
Trap	September 27-October 4	17.2
Trap	May 10-24	15.6
Control	September 27-October 4	11.1
Control	July 19-August 2	17.6
Control	November 15-29	14.8

(normal sedimentation), are inconclusive. The trends appear to be that very high sedimentation rates decrease population numbers, but more moderate sedimentation rates enhance them.

Elkhorn Slough Fish Studies

Our main objective has been to determine which habitats are important to Elkhorn Slough's fishes and to evaluate the sensitivity of these fish habitats to land and water use. We have further analyzed an existing set of fish distribution and abundance data, have made collections in previously unsampled areas of the slough, and have studied the role that the dominant fishes play in the various habitats by analyzing their seasonal distribution and abundance, their reproductive status, and by evaluating their feeding habits.

In the main channel of Elkhorn Slough, we have correlated several environmental parameters with fish catches from otter trawl samples, and have concluded that salinity and temperature may be important in regulating the distribution and abundance of only a few of the fishes living there. In general, however, most abundance patterns were weak and did not seem strongly related to any of the parameters measured. Also, we have estimated fish population densities from trawl catches in the main channel and tag return data from selected species in the slough proper and from the semi-enclosed Bennett Slough area. These densities are similar to those in other nearshore wetland environments and support the contention that fish biomass is high in such habitats. It should be noted that much of this biomass is contributed seasonally by juvenile fishes of many species. Considerable data on feeding habits have allowed us to construct a detailed trophic spectrum for fishes occurring in the main channel (Cailliet, Antrim, and Ambrose, 1978).

We have concentrated our recent efforts on the fishes occupying the tidal creeks and marsh pans, and the use that these fishes make of these shallower habitats. Study locations were chosen to typify areas that might be affected by local land use or development. In total, we made 233 collections at six locations, 170 of these with a small otter trawl, and the remaining 53 with a small beach seine. Over 9453 specimens representing 44 species were collected, identified, measured, and either returned to the capture area or preserved for further study. Approximately 300 individuals from 7 species were tagged, and only 4 have subsequently been recaptured, despite our active sampling program. This most likely indicates that there are relatively high densities of fish in these tidal creeks and perhaps also that they are highly mobile. Many of the species collected in the tidal creeks were similar to those caught in otter trawls in the channel, but more gobies occurred in the tidal creeks, and a higher proportion of the species collected there were abundantly represented by juvenile individuals. The most numerous species were *Leptocottus armatus, Atherinops affinis, Engraulis mordas, Clupea pallasii, Clevelandia ios, Cymatogaster aggregata, Gillichthys mirabilis, Platichthys stellatus, Embiotoca jacksoni, Triakis semifasciata, Paralichthys californicus*, and *Myliobatis californica* (see table 2). Most adult fishes caught were reproductively mature, indicating--along with the data on high juvenile density--that perhaps some reproductive activity occurs in these tidal creeks and marsh areas.

Seasonal peaks of fishes in the upper slough and tidal creeks were caused by transient species using the slough for short periods of time. Most of these fish were juveniles that feed in Elkhorn Slough for two to four months, later moving to the ocean. Many are important to commercial or sport fisheries (herring, halibut, starry flounder), or indirectly as forage fishes for other commercial species (staghorn sculpin, topsmelt). Since the upper slough and tidal creeks are used by fishes for reproduction (herring, topsmelt, jacksmelt, and others) and for nursery areas (herring, staghorn sculpin, anchovy, starry flounder, halibut, and others), these subhabitats are significant to Elkhorn Slough, and may qualify foremost as "sensitive areas." Also, since samples collected in these areas had higher proportions of juveniles and transient species than those from the main channel stations, we feel that the upper slough and tidal creeks are more important to offshore fish production than the main channel. of course, all of these waterways and their fish assemblages are ecologically and hydrographically interrelated.

Stomach contents have been analyzed for individuals of all dominant tidal creek species. In total, 223 stomachs from 13 species indicate that the tidal creeks harbor fishes of all trophic levels, but that small epifaunal crustaceans compose the main food source for them (figure 4). This contrasts with the trophic spectra, based on more than 1000 stomachs, for the fishes in the main channel areas. These fish feed primarily on infaunal worms and on mobile and epifaunal crustacea (Cailliet, Antrim, and Ambrose,

Table 2
Dominant Tidal Creek Fish Species Collected in Elkhorn Slough by Otter Trawl, Beach Seine, and Gill Net.

Species	Rank				Role-Activity	Seasonality
	R	%/N	R	I.V.		
Staghorn sculpin	1	33.8	1	60.3	Resident--Trans. Juv.	Spring-Juv.
Topsmelt	2	24.4	2	16.6	Trans. Juv.--Breeding Adults?	Summer-Fall?
Northern anchovy	3	14.0	3	10.9	Trans. Juv.	Spring-Summer
Pacific herring	4	7.3	4	3.3	Breeding Adult--Trans. Juv.	Adult-Winter, Juv.-sp.
Arrow goby	5	5.2	5	2.7	Resident	Year-round, Fall Peak?
Shiner surfperch	6	3.0	6	2.0	Breeding Adult--Trans. Juv.	Summer-Fall
Longjawed mudsucker	7	1.5	10	0.5	Resident	Year-round
Starry flounder	8	1.4	7	0.9	Trans. Juv.	Spring
Black surfperch	9	1.3	8	0.8	Resident	Year-round
Leopard shark	10	1.3	11	0.4	Trans. Juv.--Breeding Adult?	Spring-Summer
California halibut	11	0.9	9	0.5	Trans. Juv.	Spring-Year-round
Bat ray	12	0.9	12	0.3	Trans. Juv.--Breeding Adult?	Spring-Summer

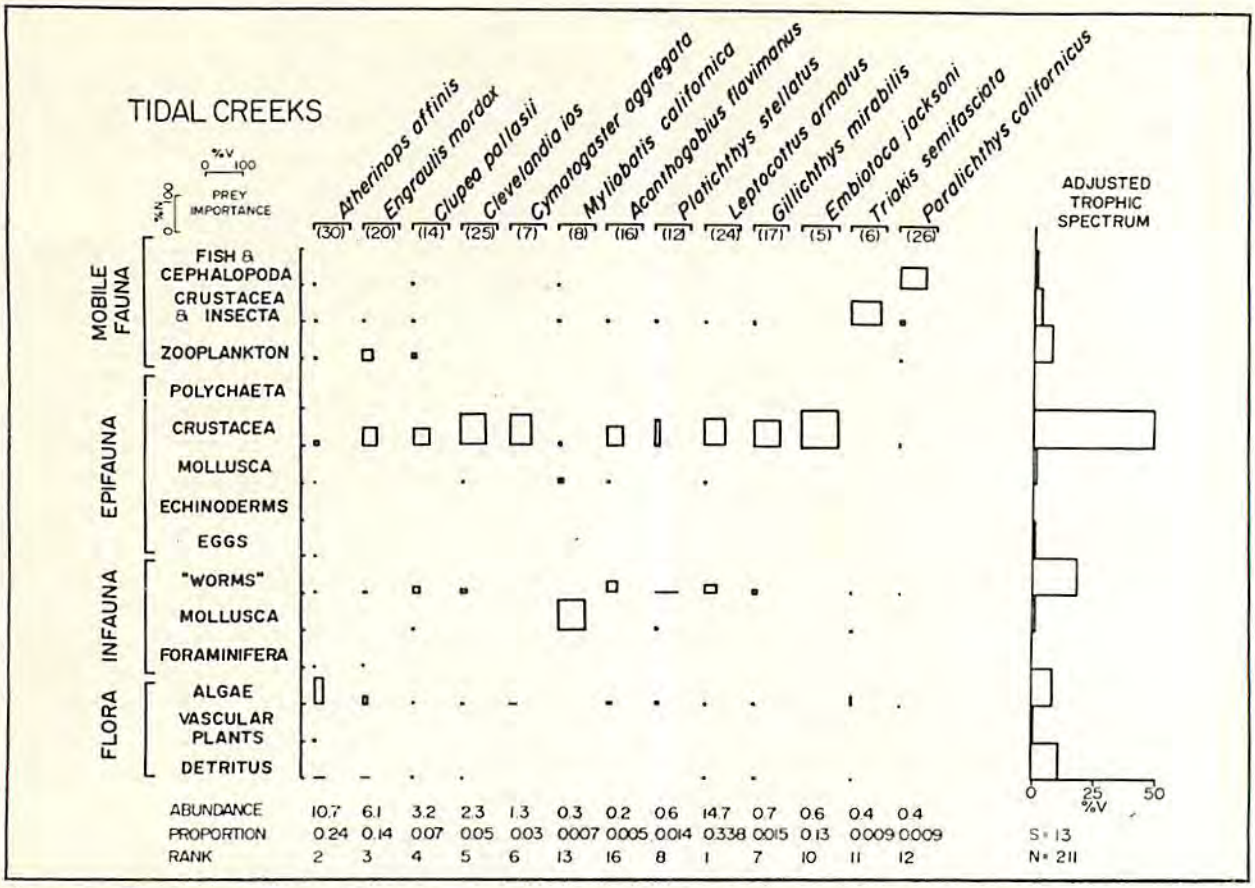

Figure 4. Trophic spectrum of the fish assemblage found in the tidal creeks of Elkhorn Slough, California. See Cailliet, Antrim, and Ambrose (1978) for details on methodology.

1978). Only three of the fish species in the tidal creeks used plant material heavily, but most fishes consumed at least some plant matter. A fish known to be a detritivore/herbivore, the striped mullet, was found in several areas of the slough, but could not effectively be sampled with our gear.

The effects of increased sedimention are difficult to assess, since fishes are highly mobile and ecologically versatile. All areas of the slough, including those with high sediment load, had abundant eggs, larvae, and juveniles of many fish species, and there was no obvious trend relating fish abundance to sedimentation processes.

In summary, all aquatic areas of Elkhorn Slough act as habitat for numerous species of fishes, but the shallow tidal creeks and salt marsh areas appear to be primarily valuable as nursery and feeding grounds. Some fishes reside in the slough all year, while others apparently visit seasonally. The density of this assemblage of fishes is high relative to other, less productive nearshore environments.

Elkhorn Slough Vegetation Study

Central California wetlands are rare and often endangered environments. Unlike the east and gulf coasts, California's coastal salt marshes are predominantly influenced by seawater and not runoff. Fresh water may dilute the channels during winters of heavy rainfall, but their salinities usually approximate that of seawater. The exception to this trend occurs during the dry summer months, when the waters in the channel of the upper slough become hypersaline. Other studies in California wetlands have examined the correlations between interstitial water salinity, periods of tidal submergence, percent soil organic matter and marsh plant distribution. However, the relationship of these three factors to vascular plant primary production remains unclear.

The objectives of this project were to describe the marsh flora, determine the primary production of the dominant plant, *Salicornia virginica*, and examine the relationship between production and abiotic gradients within the marsh. Assessments of this type are particularly applicable to an estuarine system because they provide baseline biological data that may serve to monitor the effects of land-use practices on the adjacent upland watershed.

We used the line-intercept method to compute the relative percent cover of dominant salt

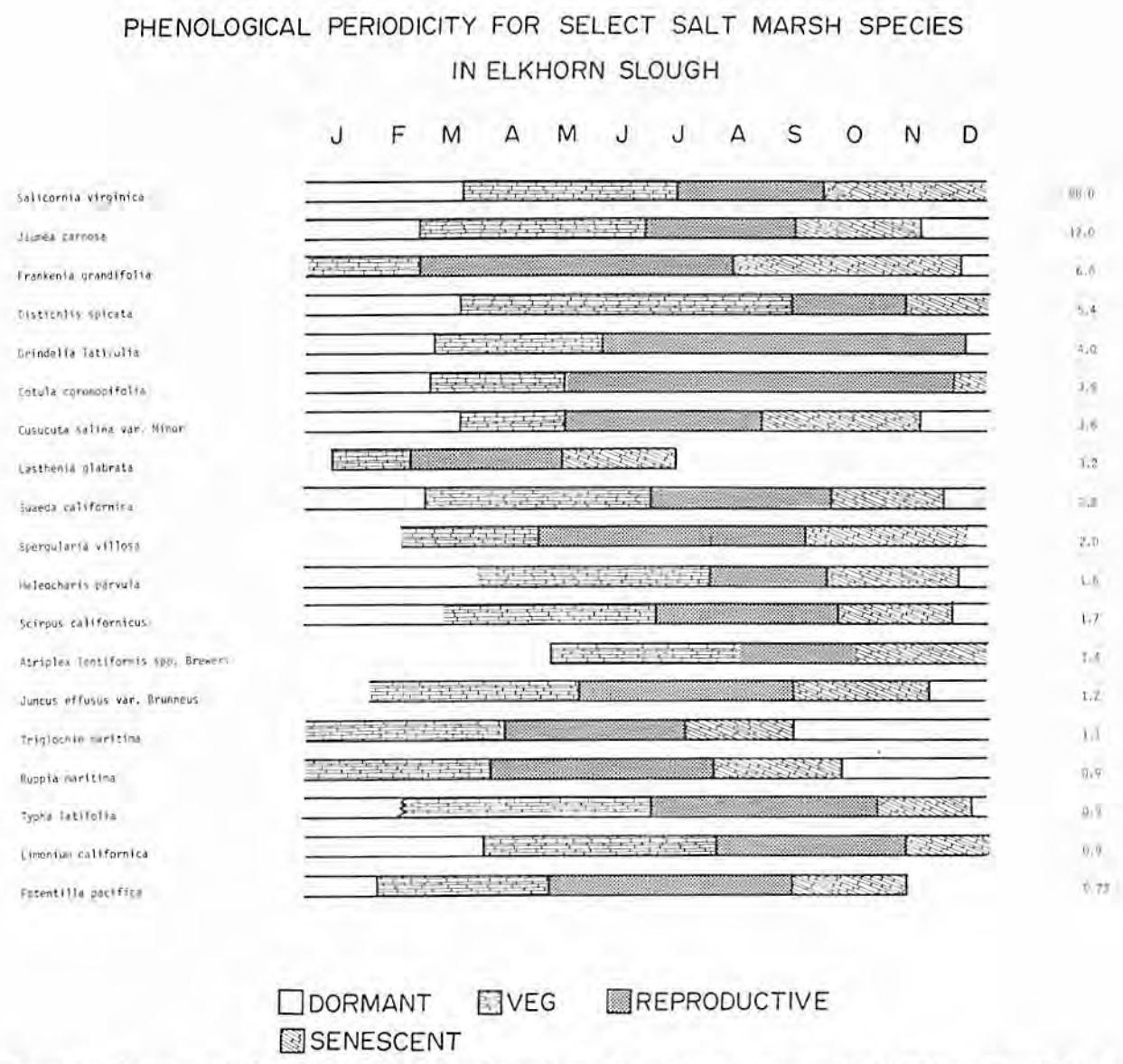

Figure 5. The seasonal phenological periodicity for various salt marsh plants occurring in Elkhorn Slough for the period between October 1978 and September 1980.

marsh plants. Overall average percent cover values were *Salicornia virginica* 88%, *Jaumea carnosa* 12%, *Frankenia grandifolia* 6%, *Distichlis spicata* 5.4%, and *Sueada californica* 2.8%. The species composition was similar throughout the study. However, species composition often varied with location. For example, the relative cover of *J. carnosa* averaged 12% throughout the marsh, but was significantly higher (42%) in the areas at the upper edge of the marsh, where sediments are deposited by land runoff.

The distribution of salt marsh species is regulated in part by different soil salinities as influenced by the tides. *Salicornia virginica* was distributed between +4.5 and +6.3 feet above MLLW. The periods of submergence at these elevations were 45.1 and 1.6 days per year, respectively. Changes in the vegetative cover of various species occurred along elevational gradients. However, percent organic matter in marsh soils had no clear relation to elevation or tidal period. Litter accumulation was greatest in the upper marsh above 5.8 feet, but the effects of this on species composition and/or productivity have not been determined. Interstitial soil salinities varied with season, with lower surface salinities occurring in the late fall and winter. During the dry months, surface salinities showed an increase due to the effect of evapotranspiration of the vegetative cover.

We also investigated phenology of these species (figure 5). *Salicornia virginica* began active growth in early April and continued until early July. In late July and August, flowers set and persisted until late September and October, when the succulent stems withered on the

woody support stems and died back. These dead stems persisted on the plant until they were either removed by tidal action or fell off during winter. Most species followed this general pattern of vegetative growth. However, there were distinct differences in the time of flowering. *Frankenia grandifolia* flowered earliest, in the late winter, whereas *Jaumea carnosa* flowered in June and July. *Distichlis spicata*, a grass, flowered later--in September and October (figure 5).

J. carnosa and *F. grandifolia* occurred in patches within stands of *Salicornia* on more elevated creek banks and small hummocks. They reached their greatest percent cover at the upland edge of the marsh adjacent to stands of *Salix* sp. (willow), in areas of freshwater seepage. The parasitic plant *Cuscuta salina* var. *Minor* (salt marsh dodder) was conspicuous on dikes and levees at elevations above MHHW (+5.5 feet) growing on its primary host *Salicornia* and its secondary host *Jaumea carnosa*. *Cuscuta* grows on, but does not parasitize, *Distichlis* and *Frankenia*. The freshwater species *Juncus effusus* var. *Brunneus* (rush), *Scirpus californicus* (bullrush), *Typha latifolia* (cattails), *Heleocharis parvula* (spike rush), and *Corona coronopifolia* (African brass buttons) were restricted to the upland edge of the salt marsh in areas of freshwater runoff or seepage. Soil salinities in these habitats varied between 2-11 ppt compared to 18-51 ppt beneath stands of *Salicornia* and *Jaumea*.

Productivity was determined by the rate of change in standing crop of live or dead plant material per unit area over the course of a year, or growing season. The annual rate of net areal primary production was calculated for the dominant plant, *Salicornia virginica*, from standing crop data over the growing seasons of 1979 and 1980. Estimates were made using standard clip-harvesting techniques following Smalley (1959). Results indicate an average annual production value for the entire marsh of 330 g DW/m^2/yr for 1979 and 480 g DW/m^2/yr in 1980. Comparisons of productivity values from all four sampling sites in Elkhorn Slough indicate few differences among the sites. However, the values for the Old Salinas River Channel sampling sites were three times as great as those recorded in Elkhorn Slough. This difference may be due in part to the greater input of fresh water and nutrients from overflows of the Tembladero Slough, the Salinas River, and the adjacent agricultural fields. Rates of primary production within all of the sampling sites varied, both temporally and spatially, with greater productivities at the higher, more landward sites in the summer. These are areas less influenced by normal tidal regimes.

Elkhorn Slough Bird Studies

Our main objectives were to quantify the number of birds using Elkhorn Slough, to describe their distribution and abundance patterns, and to determine their important feeding, resting, and breeding places. Analyzing selected species' stomach contents gave some insight into the birds' position in the slough food web.

Four slough habitats were studied--the main channel, the salt ponds, the salt marsh, and the mudflats. Censuses made here between November 1977 and February 1980 included observations on species numbers, feeding, resting, and breeding activities, and microhabitat selection.

The main channel was used by 45 species of ducks and wintering aquatic birds. Species with counts over 50 individuals were the lesser scaup, greater scaup, ruddy duck, common goldeneye, white-winged scoter, surf scoter, pintail, cinnamon teal, western grebe, and horned grebe. All are migratory, and all species except the teal and pintail fed consistently in the channel.

The salt ponds were used for loafing, feeding, and breeding. Fifty-two species were identified there. At high tide, when the adjacent mudflats were covered, the shallow ponds and protruding dikes were inhabited predominantly by hundreds of roosting western sandpipers, least sandpipers, dunlins, and dowitchers, as well as lesser numbers of marbled godwits, willets, long-billed curlews, black-bellied plovers, American avocets, black-necked stilts, gulls, terns, egrets, and herons. More than 4,000 brown pelicans also roosted on dikes in the fall. A few species fed extensively in the ponds. These included Wilson's phalarope, American avocet, black-necked stilt, and eared grebe, as well as several species of ducks. Major use of the ponds for breeding occurred in the spring and summer. Approximate numbers of breeding pairs, estimated by the number of active nests, averaged 55 western gulls, 15 snowy plovers, 90 caspian terns, and 76 Forster's terns over the three nesting seasons between 1978 and 1980 (Harvey, pers. comm.). The adult gulls and terns fed their chicks primarily on fishes caught in the slough, the Salinas River, and Monterey Bay; the gulls obtained food in similar places and from nearby garbage dumps. Snowy plovers fed in the ponds near their nests as well as on nearby beaches and at the Pajaro River mouth.

The salt marsh provided a resting area and a secondary feeding area for at least 20 species, most of which were long-legged birds such as the willet, long-billed curlew, marbled godwit, great blue heron, snowy egret, and great egret. Eight species of raptors were observed above the marsh area, one of which (the merlin) was observed feeding on shorebirds. The endangered California clapper rail was found in two marsh areas of the slough. In one of these, two pre-fledgling young were also seen.

The mudflats are the major feeding area for the shorebirds of Elkhorn Slough and the habitat most directly affected by sedimentation. Fifty shorebird censuses were conducted on the mudflats, which were subdivided into four general areas. Ten species of shorebirds fed commonly on them. Listed in order of increasing biomass, they were the least sandpiper, western sandpiper, dunlin, sanderling, long-billed dowitcher, black-bellied plover, willet, American avocet, marbled godwit, and long-billed curlew. All these except the sanderling and the long-billed curlew showed seasonal trends, with biomass and abundance increasing during the fall, remaining relatively constant throughout the winter, and decreasing again in the spring. The cumulative number for these ten shorebirds was both the highest and lowest in the spring: 60 and 22,000 birds, respectively.

The numerical abundance and biomass trends are explained in terms of the three shorebird migration patterns that were evident: (1) as exemplified by the least sandpiper, western sandpiper, dowitchers, and black-bellied plover, arrival early in the fall with passage through the area, or a lingering wintering population; (2) as in the dunlin and American avocet, arrival during late fall and over-wintering; and (3) as in the marbled godwit, willet, and American avocet, presence in the slough throughout the year.

The western sandpiper was always the most numerous shorebird in the slough, but did not always account for the highest biomass. The willet and marbled godwit contributed much of the biomass in the fall and spring. In general, shorebirds with an average weight of less than 150 g dominated in number and biomass in all seasons except the fall.

All shorebirds fed on the mudflats. It was difficult to determine if some mudflat areas held higher densities of feeding birds than others. Most variability was observed in the godwit, where mean density was highest (2.8 per hectare) on mudflats in the lower slough; or the western sandpiper, whose density was lowest on flats at the upper end (6 per hectare). Western sandpiper mean density varied between 52 and 91 per hectare in the remainder of the slough to Kirby Park. The mean density of willets varied between 6 and 24 per hectare throughout the study area, with no apparent differences between areas. Differences in densities caused by microhabitat availability and seasonal prey availability were not assessed.

The western sandpiper, marbled godwit, and willet were chosen for dietary study because of their large numbers and biomass. Birds were taken between Long Canyon and Strawberry Canyon to minimize seasonal differences in diet due to patchiness of prey. In all, 25 western sandpiper, 25 marbled godwit, and 20 willet stomachs were analyzed. Western sandpipers fed predominantly on insects, copepods, bivalves, polychaetes, and cumaceans. Marbled godwits fed on polychaetes, bivalves, and crabs. Both birds showed seasonal trends in prey taken. Willets fed mostly on the crab *Hemigrapsis oregonensis* throughout the year.

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Cooperating Organizations

California Coastal Commission
California Department of Fish and Game
Monterey County Planning and Public Works Department
National Aeronautics and Space Administration
Point Reyes Bird Observatory
State Lands Commission
University of California, Davis
U.S. Fish and Wildlife Service
U.S. Geological Survey

Geological and Historical Analysis of Coastal Zone Environmental Hazards

UC San Diego
R/CZ-43
1978-79

Francis P. Shepard and Gerald G. Kuhn

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

Our main objective was to demonstrate methods of collecting and preparing geological information essential to resource planning and management. In order to gather base information to guide detailed field investigation and mapping we compiled many existing public records such as plat maps, old land surveys, tax assessor records, aerial photographs, and Environmental Impact Statements and Reports for major projects. This information was augmented by interviews with long-term residents, information derived from newspaper files, and collections of old photographs, together with data from scientific literature.

During the first phase of the project the coastline was mapped to the inland boundary set by the California Coastal Act, 1976, on 1:24,000 scale. This scale shows the regional geology, including stratigraphy and structure, and supplements 1:2400 scale maps. All pertinent previous published and unpublished geological studies were incorporated into this phase of the study.

All known faults (offshore and onshore) were compiled on a 1:24,000 scale base. Areas subject to slope stability problems were identified.

Topographic lineations and alignments related to faulting and folding were defined through photogeological examination and interpretation of aerial photography from earliest available photos to the present. These photos were compared to each other and to recent LANDSAT, infrared, and near-infrared photography.

During the second phase of the project, the coastal zone from the southern boundary of

Camp Pendleton (San Luis Rey River north of Oceanside) south to Batiquitos Lagoon (south of Carlsbad) was mapped on 1:2400 scale orthophotogrammetric maps. This involved (1) mapping the individual geological lithologic rock units and their characteristics with relation to weathering processes and cliff erosion; (2) determining the general engineering properties of the soils and geological rock units, particularly those types of soils and rock units that are especially susceptible to erosion under natural undisturbed conditions; (3) mapping all faults, joints, fractures and sea caves that are likely to aggravate sea-cliff erosion in the form of landslides, slumps, and sloughing of the bluff-forming sands; (4) locating and monitoring the flow and effect of ground water and induced spring sapping and piping through geological units; (5) evaluating performance of existing shore protection works. All comprehensive data uncovered and researched during 1977-78 were incorporated into this final project phase.

Publications

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Cooperating Organizations

California State Lands Commission
County of San Diego
San Diego Coast Regional Commission

An Experimental Program to Develop Methods for Kelp Bed Expansion and Enhancement

UC Santa Barbara
R/CZ-46
1978-80

Michael Neushul and David A. Coon

The objectives of this project have been to experimentally examine factors limiting the distribution and standing crop of two representative kelp forests adjacent to the UC Santa Barbara campus. It has also been our goal to develop techniques for the mariculture of *Macrocystis* and other benthic marine crop plants, and to disseminate information about these techniques to others in industry, academia, and government. The two kelp forests we selected for study show variations in density and standing crop, but have exhibited relatively slow change in the positions of their margins over the years. One bed consists of plants growing on sand, whereas the other is composed of plants attached to low-relief rock.

In order to study the factors limiting kelp plant distribution, we produced juvenile kelp plants in the laboratory, and planted them along transect lines within and at the margins of the kelp beds being studied. The survival and growth of these outplantings was monitored and compared with the natural recruitment that took place. We analyzed plant survival and related it to the variations in physical factors that were measured during this two-year study.

The *Macrocystis* sporophytes used for outplanting were raised from gametophytes in the laboratory, and then grown in bubbling and shaker culture systems until they formed clumps approximately one cm in diameter. They were then separated and transferred to a special greenhouse where water motion conditions were controlled. Plants held in the greenhouse were grown until they formed a single-blade 4-10 cm long and could be attached to the floats that the plants were grown on in the sea. At each outplanting site the floats were attached to a substrate system as shown in figure 1. Nine outplantings were made at six sites in 1979-1980 over an eighteen-month period. In total, 700 plants were put into the sea during this experiment. They were judged to have "survived" if they were still alive and growing after six months.

By observing the areas adjacent to our transects we were able to contrast the success of outplants with natural recruitment even though this was extremely limited during this study. Table 1 shows the months and depths at which natural recruitment was observed. For comparison, the six-month survival of outplants is shown in figure 2.

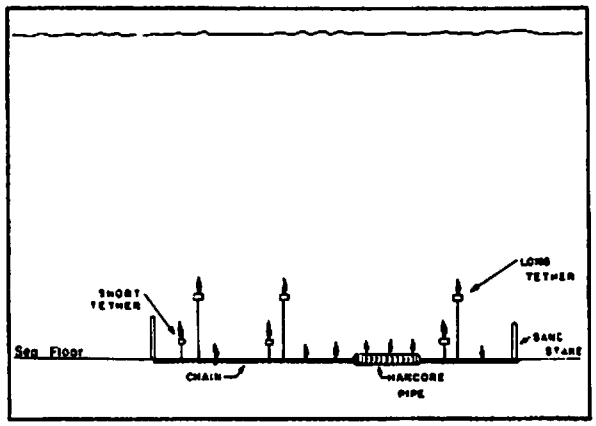

Figure 1. Substrate system.

Outplanting to sites within the kelp beds on both rock and sand shaded by canopy was uniformly unsuccessful. Under the shade of the kelp canopy the blades of the outplants became bleached, and within a two-month period sloughing increased and the plants died. Plant loss throughout these experiments was not attributable to grazing by fish or invertebrates, but to low light intensity. The maximum losses at all sites occurred during the storm periods of the year. Severe winter storms in 1979-1980 (particularly one storm in February 1980 that, in coastal impact, exceeded the 20-year record)

Table 1
Natural Recruitment Observed at Sites 1A, 2A and 4A 3/79 to 3/80

Month	Recruitment	(Depth Range)
3	+	11.6 M to surface
4	-	
5	-	
6	+	1.2 M to surface
7	+	0.1 M to 2.5 M below
8	-	
9	-	
10	+	1.2 M to near surface
11	-	
12	-	
1	-	
2	-	

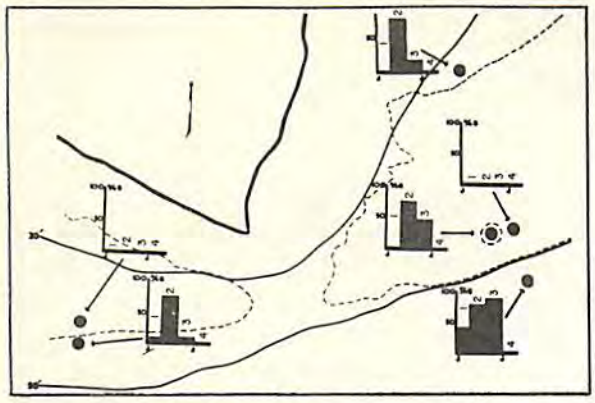

Figure 2. *Macrocystis* sporophytes were grown in the laboratory and then planted in the sea at the sites indicated, near Goleta Point. The proportion (%) of the originally outplanted plants that survived over (1) a stormy, (2) an upwelling, (3) a low nutrient, and (4) the following stormy periods are indicated for each outplanting site. Survival under the kelp canopy did not occur, but when a clearing was made (canopy is denoted by a dotted line; the canopy was removed at the outplanting site encircled by a dotted line), the outplants grew well. Different survival rates at the shallower and deeper sites were presumably related to higher nutrient levels at the deeper sites.

destroyed all the outplantings at all sites, as well as greatly diminishing the existing beds. Both water and sand motion were involved in this destruction. In some shallower sites, as much as 50 cm of sand covered the outplantings.

The deeper outplanting sites (at 45 and 50 feet) seemed to benefit from cold, nutrient-rich water during the summer months. At these sites, the nitrate nitrogen levels reached 2 to 3 μgm-at/l on occasion, while the shallower sites had nutrient levels of less than 1 μgm-at/l all of the time. The different rates of survival at shallow versus deep sites are probably due to these differences in nutrient levels.

Survival at all sites was influenced by the interplay of the timing of the plantings, ambient light levels, substrate stability, nutrient levels, water motion and sand motion, and the presence of an as yet undefined "bottom effect," which precluded the survival of any outplants directly on the sea floor during the two years of this study. The plantings that survived were on floats up above the sea floor.

Publications

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Cooperating Organizations

Goleta Sanitary District

A Study of the Entrance Problems at Humboldt Bay

UC San Diego/Humboldt State
R/CZ-47
1978-80

John D. Isaacs, Theodore H. Kerstetter, Steven L. Costa, and James W. Stork

This project is being carried out on location at the Telonicher Marine Laboratory at Trinidad, California. Our primary goal is to understand the dynamic processes controlling the operation of the entrance to Humboldt Bay in particular, and tidal inlets on sandy coasts in general. Such an understanding is imperative for intelligent planning of future modifications to the bay.

The Entrance Problems

Three distinct but interrelated problems occur at the entrance of Humboldt Bay. Two are directly related to the navigability and related maintenance of the entrance channel. The most obvious of these is the often hazardous navigation through the channel caused by severe wave action. This is a result of the inlet's orientation and location on the highest wave energy coastline in the United States. The problems are exacerbated by the bars seaward and interior to the entrance and the high tidal currents on ebb within it. The shoaling, or accretion of sand, within the entrance is also a significant problem requiring extensive dredging of the navigation channel to maintain an adequate depth for commercial shipping. The third problem at this entrance is a result of its stabilization by jetties and the deepening of the navigation channel by dredging. This has resulted in severe erosion problems at critical locations within the entrance portion of the bay (Entrance Bay) and the redistribution of this material to other locations.

Research Activities

Our research involves a three-part study of interrelated processes, to clarify the dynamics of this, and other, tidal inlets. It is necessary to understand the operation of the beach processes along the adjacent coastline, for they are the agents through which sand is supplied to the inlet. Part of the sand carried by the littoral "conveyor belt" bypasses the inlet and feeds the offshore bar; another part of the beach material is trapped within the entrance channel and requires removal by means of expensive annual dredging. The quantity of material moving along the beaches and its direction of travel are governed by the incident ocean waves on the coast. The sources, sinks, and transport paths of this material must be understood, and a budget must be constructed.

We have carried out a sampling program of the material found on the beaches and in the rivers that supply them. Close to 1000 samples have been collected at 1/2-mile intervals on the beaches between Trinidad Head and False Cape (1/10-mile intervals in the vicinity of the entrance jetties to the bay). Samples have also been collected within the entrance channel during all seasons of the year. More than 250 of the samples have been subjected to standard sieve analysis. Selected samples are being subjected to heavy mineral analysis. This is undoubtedly the most extensive sampling program carried out on this stretch of coastline. The data are being analyzed and catalogued and will be available for future studies.

The beach and nearshore processes of the Pacific Northwest differ significantly from the rest of the United States because of the severity of the wave clime. These differences are manifested not only in the magnitude of the shoreline's response but probably in the relationships between the forcing and response functions as well. Incident wave data for the coastline has been virtually nonexistent, except for untested hindcast data. Currently the Corps of Engineers and the state Department of Boating and Waterways are collecting deepwater wave data off Samoa (just north of the entrance to the bay), and these measurements will be used by the Corps to verify the hindcast predictions. At this time, however, the hindcast data and the first few months of the wave rider data are all that are available. Typical winter and summer wave energy distributions are significantly different in magnitude, direction, and distribution between sea and swell.

The second part of the investigation involves the hydraulic operation of the bay itself, as this controls the temporal and spatial distribution of velocity through the inlet. To understand this operation, we have collected, processed, and analyzed a large amount of tidal data. These data also will be archived for future investigators; again, this is the most extensive and best documented data base of its kind for this location. Under a joint agreement with the National

Ocean Survey (NOS), tide gages were maintained at five selected locations within Humboldt Bay during the second year of the project. Data are available for these and seven other stations occupied by NOS immediately prior to this time. The BCD data on punched paper tape were transferred to disk with hardware and software developed during the course of the project. Some of these data have been processed to a common datum (NGVD) and are available for computer simulation of discharge and velocity at critical points within the bay and entrance channel. (The remainder are stored in raw form awaiting further processing.) We discovered that NOS-published predictions are useful only as an index to relate the actual tidal elevations and phases to a common base. Elevations may vary by as much as 1 ft and the phases by as much as 1 hr from the predicted values.

The complex bathymetry of this bay, which is a set of three interconnected basins with extensive channelized mud flats, results in complicated interactions of the tidal variations in the various segments. This dictates the form of even the simplest computer simulation, and forces an empirical/numerical approach to the problem. The computer simulation required to predict discharge and storage quantities has been programmed. Current velocities at selected locations within the bay are used to verify the simulation. Such an approach requires various data collections for input. Tidal elevations and bay surface area are the most critical. A related project (Aerial Survey of Humboldt Bay) was funded to collect the data on surface area as a function of tidal stand. The first of these data should be available for processing in the near future.

The third part of the study is to describe the sediment transport dynamics of the entrance to the bay based on the results of the first two parts. We will then understand the stability, equilibrium condition, and shoaling characteristics of the entrance so that reasonable predictions can be made about its behavior. Future modifications to any of the agents affecting the coastline, the interior of the bay, and the entrance itself can thus be evaluated for their expected effects on the entrance. Concomitant with this goal is the identification and evaluation of procedures that may alleviate the problems at the entrance.

Preliminary Study Results

The problems engendered by the severe wave action in the entrance are the most hazardous to users of the bay and the most difficult to deal with. The most immediate solution would be the ability to predict conditions in advance. This involves a knowledge of nearshore parameters such as bathymetry and tidal currents, as well as the mid-ocean wave climate that will cause future nearshore wave conditions: the former are or soon will be available; the latter are generally unknown. One possible solution would be to monitor the location of storm tracks using available satellite weather maps, and the relative intensity of storm-generated waves by means of their microseismic signature. Preliminary studies indicate that this is feasible. Funding has been obtained to support a one-year study by a Humboldt State graduate student addresssing this approach in detail.

The intense shoaling of the entrance channel is a pervasive and expensive problem requiring annual dredging. From the distribution of tidal flows in the bay one would expect an ebb-dominant or natural flushing mode of operation for this entrance. The severe shoaling of the channel is contrary to this observation, and one would thus conclude that the inlet is not in equilibrium. However, considering the tidal-prism inlet area relationship, it is seen that the project depth of the navigation channel is approximately on the "equilibrium line." The paradox is understood by considering that the natural ebb channel is not in the location of the dredged navigation channel. The site of the dredged channel is located to minimize maintenance of the channel over the outer bar, and does not follow the route of the naturally scoured ebb channel within the entrance.

Possible solutions would involve realigning the navigation channel, and bypassing the outer bar (crater-sink scheme, for example). Properly designed, this could also decrease the wave problems within the entrance. Other approaches would involve major reconstruction of the entrance or modifications to the tidal prisms of various parts of the bay's interior basins. These would be quite expensive and, most likely, environmentally unacceptable. These and other schemes are being evaluated and will be presented in detail in our final report. Our investigations have led to a better understanding of the dynamics of tidal inlets and the fundamental basis underlying the tidal prism-inlet area relationship.

The shoaling of the inlet is intimately linked with the nature of the littoral transport on the adjacent beaches. The operation of this littoral cell is significantly different from those previ-

ously described. From the information gathered on sediment characteristics and the available incident wave data, it is obvious that the behavior of the Humboldt Littoral Cell is somewhat different from previous descriptions. In the winter months (December - February) there appears to be a net northward transport in a wide offshore zone. During the rest of the year the transport appears to be southward, but less intense and in a much narrower offshore region. The most severe shoaling seems to occur during the intense winter episodes: most of the summer littoral drift bypasses the entrance around the offshore bar. If there is a net drift annually, it is probably south to north. The case for an episodic winter shoaling of the entrance is supported by reports of pilot boats. The classical longshore transport equations do not seem to fit the high wave energy coastline found in the northwest. It appears that these equations can be modified without any loss of their present application.

Humboldt Bay is a system of three interconnected shallow basins in which the interaction of the tidal flows and the bathymetry cause a tidally pumped circulation in Entrance Bay that has been qualitatively documented. Although it is only peripherally related to the main objectives of this study, we are evaluating its importance and seeking further funding to extend the study. Such circulation is quite important in its relation to pollutant dispersal and flushing, nutrient distribution, and the viability of commercial and sport fisheries within the bay.

Stabilization and deepening of the entrance channel since construction of the twin jetties and numerous dredging projects has led to major modifications in the physical processes in adjacent regions. The shoreline of Entrance Bay has undergone significant erosion and redistribution of material. Severe erosion is encountered in some sectors, and a large spit has developed over the last fifty years. We are preparing a paper on this topic, based largely on the historical data uncovered during the initial phases of this project.

Publications

Pascal plotter subroutines for the HiPlot plotter. *Byte Journal of Small Systems* (Spring, 1981).

Cooperating Organizations

Army Corps of Engineers
Evans-Hamilton Co.
Humboldt County Department of Public Works and Department of Natural Resources
National Ocean Survey
Oregon State University
Regional Water Quality Control Board
U.S. Coast Guard
Winzler and Kelly, Inc.

Coastal Wetlands Management: Restoration and Establishment

San Diego State
R/CZ-51
1979-80

Joy B. Zedler

To provide guidelines for the restoration and establishment of wetland communities, we have set as our goals (1) determining what regulates the natural growth of salt marsh species, and (2) testing methods of propagating native southern California marsh plants, using different field populations of marsh plants as sources of propagules.

Salt Marsh Dynamics

We owe a major part of our understanding of variation in natural salt marsh vegetation to long-term observations under variable environmental conditions. Because we had been examining the structure and productivity of salt marsh vegetation since 1977 in three wetlands (R/CZ-33C and Zedler et al., 1980), it has been possible to assess changes brought about by different types of freshwater influences. In addition, monitoring of salt marsh soils and vegetation at Tijuana Estuary since early 1979 made it possible for us to follow specific changes in soil salinity, and in *Spartina foliosa* height, density, and flowering brought about by the 1980 floods.

Our comparisons led to a conceptual model that specifies how the interaction of fresh water and tides controls the structure and productivity of salt marsh vegetation in southern California (figure 1). Initially, the input of fresh water

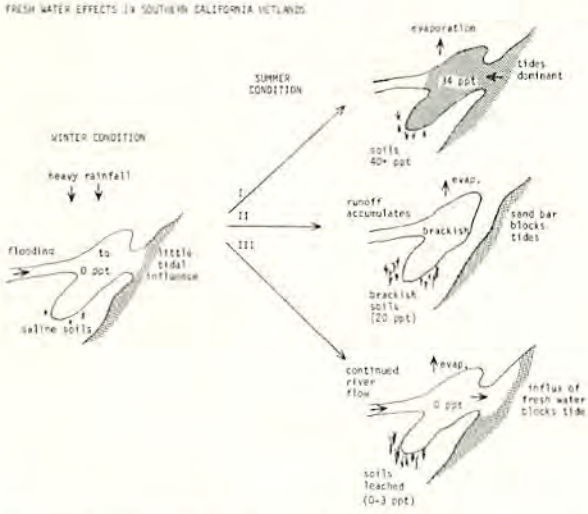

Figure 1. The effect of runoff on arid region wetlands depends both on the duration of the inflow and the influence of tidal seawater. Three case studies are described with increasing impacts on wetland soils and vegetation.

dilutes an estuary's normally saline (≃34 ppt) water. However, the ultimate impact of the fresh water depends on the tidal features of the estuary, exemplified by three case studies described below:

Case I: Freshwater input with no long-term alteration of tidal influx (Tijuana Estuary, 1980). An unusually large input of fresh water brought debris and sediments into the salt marsh of the Tijuana Estuary. Water remained in the estuary long enough to leach salts from the usually hypersaline soils. Whereas soil salinity remained above 34 ppt throughout 1979, the April 1980 average was 14.8 ppt (table 1).

Table 1
Changes in Interstitial Soil Salinity at Tijuana Estuary

Transect	Spring 1979		Fall 1979 (Oct. 2)		Spring 1980 (Apr. 3)	Fall 1980 (Sept. 17)
TJE-2			45.6	(3.2)	24.7 (3.6)	41.8 (4.2)
TJE-5			42.1	(1.6)	14.1 (2.8)	44.3 (5.8)
TJE-28	June 11:	40.0 (4.8)	45.8	(3.0)	15.8 (5.3)	36.8 (1.9)
TJE-30			47.8	(4.7)	13.4 (4.1)	42.5 (5.1)
	April 17:	35.0 (4.1)				
TJE-31			39.8	(13.7)	14.3 (6.4)	41.7 (6.1)
	May 3:	36.7 (4.7)				
TJE-33			42.8	(1.8)	12.8 (4.1)	40.0 (4.8)
TJE-34			44.2	(1.7)	13.9 (3.9)	43.0 (4.0)
TJE-37	June 11:	41.2 (4.0)	45.9	(7.9)	13.4 (4.6)	38.7 (5.2)
Overall mean		38.7 (4.9)	45.1	(4.4)	14.8 (5.4)	41.0 (5.1)
n		41	99		99	99

Data are ppt (mean and standard deviation)

This decrease in salinity, along with sediment accretion (and presumably nutrient input) appears to be responsible for a dramatic increase in the growth of *Spartina foliosa*, as measured by a 19 cm increase in average height, a 30 cm increase in maximum height, and an average increase in density of 17 individuals per m^2 (table 2). Biomass of *Spartina foliosa* vegetation was 40% higher in August 1980 than in previous years (figure 2).

Freshwater input seems also to have allowed significant expansion of *Spartina foliosa*'s distri-

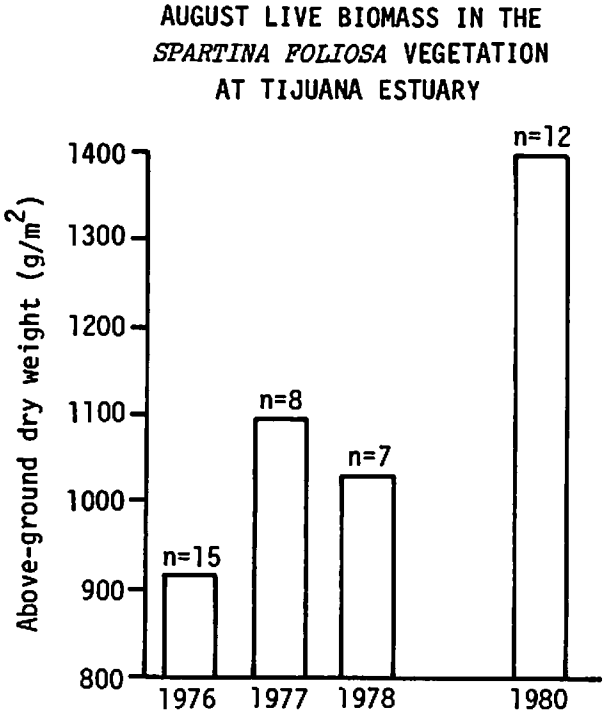

Figure 2. The August biomass of *Spartina foliosa* was 40% higher in 1980 than 1978, a response attributed to runoff and a short-term reduction in soil salinity.

bution at Tijuana Estuary. In an abandoned sewage lagoon, where we had previously censused and marked 33 patches of *S. foliosa* (March 1979), we found 103 patches in June 1980. While some of the expansion may have been due to vegetative reproduction, we saw seedling establishment for the first time.

Case II: Freshwater input with blocked ocean connection (Los Peñasquitos Lagoon, 1978). Rainfall in 1978 did not lead to massive flooding as in 1980; however, in lagoons blocked by sand bars, freshwater impoundment can persist and leach salts from the marsh soils. The brackish soils that prevailed during spring of 1978, along with nutrients from runoff and decomposition, apparently doubled the productivity of *Salicornia virginica* vegetation in Los Peñasquitos marsh (Zedler et al., 1980). This productivity response was substantially greater than that of Tijuana Estuary, where the tidal influence returned after winter flooding. (Case I).

Case III: Continuous freshwater input. This rarely occurs in arid region wetlands. However, with the drawdown of upstream reservoir levels as a flood-protective measure in 1980, the San Diego River had sufficient flow to prevent tidal waters from influencing the flood control channel (FCC) marsh.

The impact of flooding and prolonged freshwater input altered the entire structure of the FCC marsh. Prior to 1979, the area was nearly a monotype of *Salicornia virginica* (Zedler et al., 1980). But the long period of inundation and thorough leaching of salts from the soil killed much of the salt marsh vegetation and provided suitable conditions for invasion by freshwater marsh species. The marsh is now dominated by cattails (*Typha* species), which invaded and grew to 2 m height in 4-5 months (figure 3). By Sep-

Table 2
Changes at the Tijuana Estuary Salt Marsh
September 1979 to September 1980

		Changes in *Spartina foliosa*				
Transect	Change in Elevation (cm)	Density (#/m²)	Mean Height (cm)	Mean Ht x Den (m/m²)	Maximum Height (cm)	Flowering (#/m²)
TJE-2	↑ 4.7 *	NS	NS	NS	NS	NS
TJE-5		NS	↑ 4.9 **	NS	↑ 15.1 **	NS
TJE-28	↑ 7.2 *	NS	↑ 3.3 **	NS	↑ 32.4 *	NS
TJE-30	↑ 6.9 **	↑ 26 ***	↑ 4.2 **	↑ 2.7 *	↑ 31.4 ***	NS
TJE-31	↑ 4.4 ***	NS	↑ 3.6 *	NS	↑ 21.6 ***	↓ 8 *
TJE-33	↑ 2.5 **	↑ 26 ***	↑ 9.7 **	↑ 2.2 *	↑ 26.4 ***	NS
TJE-34	↑ 9.2 ***	NS	↑ 16.7 ***	↑ 2.5 *	↑ 25.4 ***	↑ 18 **
TJE-37	NS	↑ 18 ***	NS	NS	↑ 20.4 ***	NS
Average for 101 quadrats	↑ 4.4 cm	↓ 17/m²	↑ 19 cm	↓ 1.9 m/m²	↑ 30 cm	↑ 3.6/m²

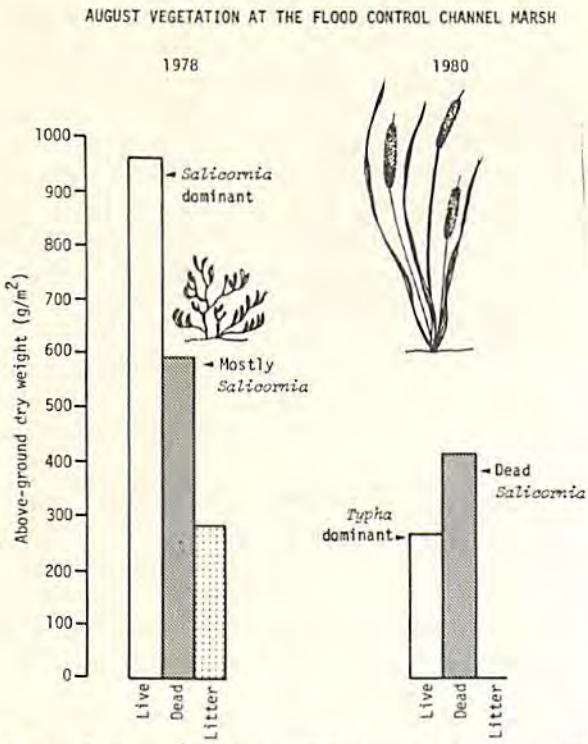

Figure 3. Long-term input of fresh water to one marsh changed species composition from salt marsh to fresh water marsh vegetation.

tember 1980, the above-ground productivity of the new cattail community had equalled that of the previous *Salicornia virginica* marsh, but the standing crop was far below that of mature cattail stands upstream. If freshwater flow continues at similar rates, the new cattail community can be expected to mature in the next year or two; however, if saline conditions recur, I predict high mortality and a gradual return of *Salicornia virginica.*

Together, these three case studies demonstrate how the structure and productivity of arid region wetlands respond to freshwater input. Under average conditions, salt marsh soils are hypersaline, and the vascular plants are low in productivity (net above-ground dry weight of about 1 kg/m^2/yr). A small or temporary influence of fresh water can increase their productivity somewhat (Case I); a prolonged influence increases their productivity greatly (Case II); and a continual influence can change the entire character of the wetland from saline to freshwater marsh (Case III).

It is not recommended that these changes in vascular plant productivity be used in making value judgments about the marsh vegetation, however, since increased productivity of these plants can be expected to decrease productivity of the understory algae (Zedler, 1980). We predict that freshwater input affects the entire ecosystem, altering the types of food sources available and the productivity of higher trophic levels (Zedler et al., 1980).

Propagation of Salt Marsh Vegetation

Because of the importance of *Spartina foliosa* to wildlife such as the endangered light-footed clapper rail (Jorgensen, 1975), and because *S. foliosa* rarely invades new habitats in southern California, we have concentrated our propagation efforts on this species. We have attempted to grow seeds, rhizomes, and whole plants under a variety of environmental conditions, seeking to maximize survival, growth, and reproduction.

A summary of data on our success in growing seeds to maturity can be viewed as average survivorship for 100 seeds assumed to be viable from their robust appearance:

100 seeds	→	47% 47 germinate in petri dishes	→	80% 38 survive to be potted	→	48% 18 survive potting	→	95% 17 survive for field transportation

As the survivorship percentages show, the germination and early seedling stages are critical in rearing individuals to maturity. To date, we have identified several factors that reduce survivorship at these stages, and additional experiments are planned for 1980-81. After collection in late fall, seeds are stored at 5°C. The salinity of storage water (fresh, brackish, seawater) does not alter germination rates, but salinity conditions during germination do appear to be important (experiments in progress). Storage time affects germination, with lowest rates for seeds stored 7.5 months, and highest rates for seeds stored 1 month, although 0.5 month was insufficient for maximum germination. In all cases, germination after cold storage continues for long periods, usually terminating after two months of observation in growth chambers (figure 4). *Spartina foliosa* has strong dormancy tendencies under both cold (5°C storage) and warm (15-25°C growth chamber) conditions. Future experiments will attempt to improve germination.

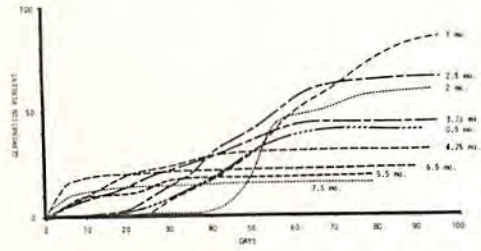

Figure 4. Seed germination curves for *Spartina foliosa* stored for different time periods at 5°C in brackish water (70% seawater).

Figure 5. *Spartina foliosa* patch 1½ years after planting a single shoot.

Early seedling survival was higher under greenhouse conditions than outdoors, suggesting that exposed mudflats are poor environments for seed reproduction of *Spartina foliosa*. Further experiments, e.g. varying light, will seek to identify mortality-causing factors at this stage.

Propagation from rhizome segments is not likely to be feasible. Our attempts to grow 1-node, 2-node, and tip sections of the rhizome in pots and in floating aquaculture under various salinities used well over 100 propagules, but only a few of the tip sections produced whole plants.

Transplantation of shoots (whole plants collected from the field) is a proven technique for establishing *Spartina foliosa* in mudflats (figure 5), given that soils are not too saline and that herbivores are controlled. However, natural sources of *S. foliosa* are limited in southern California, and artificial propagation is essential for large transplantation projects. Experiments to maximize survival, growth, and reproduction of shoots and of young seedlings all suggest that fresh water provides the best laboratory environment for this halophyte (e.g. data for shoots in table 3).

While it may be most profitable to grow and propagate *S. foliosa* in fresh water, such individuals may suffer greater shock upon transplantation to hypersaline mudflats. Thus, we are determining the survival and growth of laboratory-reared plants set out in salt marsh habitats. This, then, will form the last link in developing a program to collect, grow, propagate, and transplant *Spartina foliosa* for the establishment and enhancement of southern California wetlands.

Table 3
Effect of Salinity on Survival, Growth and Flowering of *Spartina foliosa* Shoots

	% Survival	Average Maximum Height (cm)	% Flowering
Seawater (34 ppt)	38	48	4
Brackish (about 20 ppt)	91*	67	20
Fresh water (0-1 ppt)	128**	77	57

*Includes production of new plants by tillering.
**These plants had high survival and produced several new plants by tillering.

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productivity with natural and altered tidal circulation. *Oecologia* 44: 236-240.

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Cooperating Organizations

California Department of Parks and Recreation

U.S. Department of Interior Fish and Wildlife Service

U.S. Navy Wildlife and Natural Resource Office

University College of North Wales, Marine Biology Department

Coastal Wetlands Management: Application of Biological Criteria

UC Santa Barbara
R/CZ-52
1979-80

Christopher P. Onuf, Robert W. Holmes, and Charles H. Peterson

The conservation and enhancement of natural resources are very important in California's coastal zone management program as set forth in the Coastal Act of 1976. Coastal wetlands are explicitly identified as "sensitive coastal resource areas" in the Act. The last few years have made it obvious that coastal wetlands indeed *are* sensitive areas, particularly to episodes of heavy sedimentation. Ordinarily these episodes are rare occurrences in this arid region. Decades may pass between events. This makes it difficult to determine the effects of the incidents and to ascertain their importance compared to the much longer periods of less extreme conditions. If management of the natural resources of coastal wetlands is to be effective, it must encompass these infrequent but major events.

Our study of the lagoon-salt marsh ecosystem at Mugu Lagoon now spans two of these usually rare events. The year of 1978 was the second wettest in the 113 years for which local records are available. Precipitation has been less during 1980, but one storm caused a 100-year flood. Its effects on the lagoon were diminished by the breaching of levees on the entrance stream before it emptied into the lagoon. Even though vast quantities of sediment were dropped on the Oxnard Plain in the vicinity of the breaks in the levees, a new layer of 5-10 cm of sediment was deposited over most of the subtidal parts of the lagoon. This has set back our assessment of the duration of effects from catastrophic sedimentation.

On the other hand, the repetition of the process will allow us to test the validity of the conclusions from our analysis of the first episode. Given the large (but largely uncharted) inherent variability of these systems, this is a valuable opportunity to verify whether the changes that we observed after the first episode of flooding were actually caused by the flooding and sediment deposition or only correlated in time. This replicated analysis will permit us to make much more reliable predictions for the management of wetlands than would have been possible based on the 1978 event alone.

Progress to Date

We previously reported a stimulation in the growth of *Salicornia virginica*, the dominant plant of the salt marsh at Mugu Lagoon in the growing season after the flooding of 1978. This was followed by a return almost to preflood levels during the growing season of 1979. Again in 1980 we have documented a stimulation in growth in the growing season after flooding. On this basis we are predicting with some confidence that the growth of new green material will fall off again next year (barring a third "rare" event in four years). Thus, the effect of flooding on salt marsh productivity is positive but short-lived. It remains to be determined whether longer-term changes will follow, such as changes in species composition. None are evident so far.

The response of the fishes of the lagoon is quite different from that of the marsh plants (see table 1 on page 28). The response to the 1978 inundation was in net a moderate reduction in numbers distributed among almost all species present. Most of the rare species of 1977 were not caught in 1978, so that the most striking change was the reduction in the number of species. Unlike the salt marsh, there was only a slight indication of a return to pre-1978 flood conditions even in the second year after the sedimentation. Also unlike the salt marsh, response of the fishes to the second episode of flooding and sedimentation was qualitatively different from the response to the first. Rather than a slight reduction in number and a major reduction in number of species, there was a major reduction in number and no change in number of species. It is as if the main effect of the first flood was to change the lagoon qualitatively, so that it provided suitable habitat for fewer kinds of fishes; whereas the main effect of the second flood was to change the lagoon quantitatively, so that it could support fewer fish.

This speculation is consistent with the gross changes in kind that were evident in some areas after the 1978 flood but not after the 1980 flood; i.e., the elimination of the eelgrass bed at one sampling station and the deposition of a much finer sediment than had previously been present at another sampling station. The same stations received another thick mantle of sediments in 1980, but this caused no obvious change in bottom type, as it had in 1978.

Another development in our fish study is that, in face of a decline of almost 50% in total

number of fish between 1977 and 1980, the two most important flatfish of the lagoon--California halibut and diamond turbot--have increased 79 and 16% respectively. If this situation persists, it warrants further study. Insight into the habitat requirements or preferences of flatfish would be valuable for designing restoration projects, since enhancement of fishable stocks is a major objective of California's coastal zone management efforts.

An important aspect of the management of coastal wetlands is the restoration of areas that have been degraded, usually by human alterations of surrounding landforms, to a condition that will support a greater variety or quantity of native plants and animals. This is particularly important in the case of central and southern California coastal wetlands, because several of their indigenous species are rare or threatened with extinction. We are studying bird utilization in different parts of Mugu Lagoon to ascertain the consequences of increasing tidal flushing, a commonly proposed procedure for restoring coastal wetland ecosystems.

The mouth of the western arm of Mugu Lagoon was opened to virtually unrestricted tidal flow in January 1979, after approximately twenty years of reduced flushing, when the culvert in the causeway crossing the mouth was replaced with a bridge. We now have records of bird utilization for two fall migration periods before the widening of the mouth and one after, together with one spring migration and summer residence period before and two after the increase in flushing of the western arm. By comparing our census areas in this part of the lagoon with our other census areas in the unaltered parts of the lagoon, we can distinguish changes in bird use in the western arm that can be attributed to the alteration, even while large changes in numbers are occurring for the lagoon as a whole and for the entire Pacific flyway. It is apparent that the abundance of birds fluctuates widely between years even in the unaltered eastern arm (table 1). This obviously makes it more difficult to identify the effect of the change in the western arm. Nevertheless, the difference between the changes in numbers in the western arm compared to the eastern arm is consistent for all four possible comparisons for both categories of shorebirds. This strongly suggests that opening the western arm has improved it as a habitat for shorebirds. In contrast, the difference for dabblers (dabbling ducks and coots) has been consistently in the opposite direction, suggesting a change for the worse for this group.

Our studies in Mugu Lagoon are revealing considerable complexity. This suggests that the job of good management for natural resources will be hard to accomplish. Nevertheless, we are beginning to discriminate some consistent patterns, even in the presence of the large inherent variability of coastal wetlands ecosystems. These findings will be invaluable in future management of this rare and sensitive resource.

Publications

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Table 1
Percent Change in Mean Abundance of Water-Related Birds Before the Opening of the Western Arm to Increased Tidal Flushing in January 1979

	Fall migration periods						Summer migration and summer residence periods					
	1979 vs. 1977			1979 vs. 1978			1979 vs.. 1978			1980 vs 1978		
	W	E	Possible effect of the alteration	W	E	Possible effect of the alteration	W	E	Possible effect of the alteration	W	E	Possible effect of the alteration
Shorebirds												
Probing feeders	+13	-32	Increase	+106	+4	Increase	+26	-30	Increase	+90	+23	Increase
Surface feeders	+89	+59	Increase	+138	0	Increase	+92	-16	Increase	+16	-37	Increase
Fish eaters	-60	+7	Decrease	-26	+48	Decrease	-43	-40	No change	+5	-30	Increase
Mollusc eaters	-23	+69	Decrease	-8	-3	No change	-68	+18	Decrease	-23	-31	No change
Dabblers	+6	+66	Decrease	-31	+146	Decrease	-40	+52	Decrease	-63	-7	Decrease
Gulls	+163	+87	Increase	-87	+181	Decrease	+200	-8	Increase	0	+292	Decrease

W = western arm (altered), E = eastern arm (unaltered).

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Cooperating Organizations

U.S. Fish and Wildlife Service, Laguna Niguel, California
U.S. Navy Air Station, Pt. Mugu, California

Investigation of Coastal Bluff Retreat for the Trinidad Headland Area of Northern California

Humboldt State
R/CZ-53
1979-80

Gary A. Carver, Kenneth R. Aalto, Elmont A. Honea, and Derek Rust

The coastline in northern California is generally emergent and characterized by prominent headlands with sea cliffs, bluffs, and steep coastal slopes. Coastal geologic processes at work along this coastline vary from place to place.

Coastal slope and bluff erosion processes and rates may reflect local rock type, structure, tectonic and geomorphic setting, and transient seismic, meteorologic, wave, and tide conditions.

The major goals of this project have been: (1) to develop detailed geologic and geomorphic maps covering the study area, (2) to determine historical coastal retreat or erosion rates and events at specific coastal sites, and (3) to monitor the slope movement of several large coastal landslides.

Geologic and Geomorhic Mapping

We have completed preliminary geologic and geomorphic maps for the coastal strip between Little River and Dry Lagoon. These preliminary maps (scale 1:6000) are based on detailed field recognizance of the entire study area, detailed interpretation of 1:12000 scale black-and-white aerial photographs (1974), and analysis of numerous additional photographs, remote sensing images, and published and unpublished geologic maps and reports.

Historic Coastal Retreat Studies

Documentation of historic coastal retreat and coastal erosion has included identification, location, acquisition, and curation of several hundred photographs, surveys, and maps covering more than a hundred-year period. Selected aerial photographs taken in 1931, 1941, 1942, 1947, 1955, 1964, 1968, and 1970 have been enlarged to approximately 1" = 200', and coastal sites compared on successive photographs. Preliminary analysis of historic coastal erosion has resulted in the development of coastal retreat amounts and rates for periods of 30 to 100 years at 41 sites within the study area, and the characterization of retreat patterns and rates for the historic period throughout the study area. Distinct erosional and retreat processes and patterns reflect strong lithological, structural, and geomorphic control within the study area. Three general coastal geologic and geomorphic terrains have been identified and characterized by distinct and different erosion and retreat histories.

We installed five permanent landslide movement monitoring stations on two large, complex coastal landslides. These stations were operated from January through May 1980. During the summer of 1980 we modified the monitoring network, and added two portable monitoring stations. The five permanent stations commenced operation for the 1980-81 storm season in October. Five monumented survey lines have been established on the two landslides, and we have completed three re-surveys.

Publications

Horan, E.P. The influence of bedrock composition and structure on coastal slopes and associated types of failure in northern California. Student thesis, Jan. 1980.

Cooperating Organizations

Humboldt County Department of Public Works

Analysis of Coastal Ocean Mixing Models

E. John List and James J. Morgan

In the past year we have concentrated our research on two major aspects of the problems associated with the discharge of fine particulate matter to coastal ocean waters.

First, a new theory for predicting particle size distributions has been developed. This research, which formed the basis of James Hunt's Ph.D. thesis at California Institute of Technology, extended an earlier theoretical analysis of atmospheric aerosol size distribution dynamics. The theory, based on the idea of self-similarity of particle size distributions, enables predictions to be made for particle sizes over the ranges where four different mechanisms influence the particle sizes. These mechanisms are Brownian motion, fluid shear induced by the ocean motion, differential sedimentation, and particle settling. The results are represented by size distribution density function n(d) so that number of particles of diameter between d and d+Δd is given by n(d)Δd.

The basic assumption is that only one coagulation mechanism is dominant in any given particle size range. Brownian motion is dominant for the smallest sizes, shear-induced coagulation for intermediate sizes, followed by differential sedimentation and gravitational settling. The particle size distribution is also assumed to be in a dynamic steady state; that is, the flux of particle volume, E, or equivalently the flux of total particle mass, is constant. Using these basic assumptions, Hunt was able to predict theoretically that for Brownian motion

$$n(d) = A_b \left(\frac{E}{K}\right)^{\frac{1}{2}} d^{-5/2}$$

and for fluid shear

$$n(d) = A_s \left(\frac{E}{G}\right)^{1/2} d^{-4}$$

and for differential sedimentation

$$n(d) = A_d \left(\frac{E}{S}\right)^{1/2} d^{-9/2}$$

and for settling

$$n(d) = A_g \left(\frac{E}{S}\right)^{3/4} d^{-17/4}$$

where A_b, A_s, A_d, A_g are constants, $K = kT/\mu$ where k is the Boltzmann constant, T is the absolute temperature and μ the fluid viscosity, G is the mean fluid shearing rate, and S is the sedimentation and settling coefficient $g(\rho_p - \rho_f)/\mu$, with $\rho_p - \rho_f$ the difference in the particle and fluid densities.

The theoretical predictions for the Brownian and shear coagulation mechanisms were verified experimentally using three common clay minerals. The results are immediately applicable to the prediction of particle size distributions in seawater, as well as a wide range of industrial processes, including wastewater treatment.

Application of the above results to coastal seawater requires knowledge of the mean fluid shearing rates appropriate to coastal waters. This was the second objective of our research in the past year. In order to determine mean fluid shearing rates in coastal ocean waters, it is necessary to determine the rates of strain associated with the distortion of fluid elements by turbulence. While this has been done previously, for a well-mixed and highly turbulent ocean--and with great difficulty, it might be added--there is essentially no ocean field data on the role of density stratification in the inhibition of the straining. Drs. Gregory Gartrell and John List are in the process of converting to field use a laser-Doppler velocimeter that has successfully accomplished this goal in the laboratory.

The design of the laser-Doppler system for field use has gained a significant amount of international attention, and there have been numerous visitor requests for design details. Making the laser-Doppler system operational and obtaining actual field data will be the primary goal of the forthcoming year.

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Cooperating Organizations

Environmental Protection Agency
National Oceanic and Atmospheric Administration
National Science Foundation
The Mellon Foundation

Phosphorites Along the Central California Continental Margin

San Jose State
R/CZ-54
1979-80

Henry T. Mullins, H. Gary Greene, and John H. Martin

Phosphorites are of economic value primarily as a source of agricultural fertilizer, but also are now considered to be a possible source of uranium. In October 1979, we initiated a resource assessment of phosphorite deposits along the central California continental margin. Such an assessment of offshore phosphorites involves information on their distribution, depth, and density of occurrence as well as their mineralogical and chemical composition. Our secondary objective was to collect data on the age, origin, and diagenesis of these phosphorites.

We have spent a total of fourteen days at sea collecting rock dredge and grab samples as well as bathymetric data (figure 1). Our results to date indicate that major phosphorite deposits occur offshore of Point Sur, Cape San Martin, and Pescadero Point. In each area, the phosphorites are found in relatively deep water (800-1400 m). Our results also indicate that *major* phosphorite deposits are *not* present in Monterey Bay, off Point Reyes, or seaward of the Farallon Islands. Phosphorites, if present in these areas, are probably patchily distributed and of minor importance.

All of our phosphorite samples have been described, subsampled for geochemical analysis, slabbed, and thin-sectioned. We have also initiated preliminary laboratory analyses. Elemental composition of the phosphorites, including uranium, is presently being determined by neutron activation analysis at the University of California, Berkeley. Preliminary data on the phosphorus content (via spectrophotometric and colorimetric techniques) of selected subsamples have been compiled. Our data indicate that the phosphorites off Point Sur contain 28-33% P_2O_5 values, which are relatively high. Phosphorites with more than about 15% P_2O_5 are considered minable.

We have also conducted preliminary analyses of the mineralogy (via X-ray diffraction) and texture (via X-radiography and petrographic examination of thin sections) of these phosphorites. Mineralogically, the phosphorites are dominated by the mineral francolite, with minor quartz, feldspar, and micas. Glauconite was found to be locally abundant, and at times serves as nuclei for concentrically laminated phosphorite pellets. Texturally, these phosphorites are heavily mottled or bioturbated, and have a distinct pelloidal matrix with numerous phosphorite pellets.

The absolute age of these phosphorites is not known. We plan to have samples dated by U-series methods to ascertain whether they are contemporary (i.e., < 800,000 years). There are very few fossils contained within the phosphorites; thus, age determination by biostratigraphic techniques may be difficult. However, we suspect that these offshore deposits may be correlative with onshore phosphorites that are of Miocene age.

All of our data suggest that the central California continental margin phosphorites formed in a dysaerobic environment characterized by dissolved oxygen concentration of 0.01 to 1.0 ml/l. This interpretation is based on the heavily mottled (i.e., burrowed) texture of the phosphorites coupled with a paucity of hard-bodied fossils. Modern dysaerobic environments are characterized by a soft-bodied infauna and a lack of hard-bodied organisms. It is also likely that these phosphorites formed within a coastal upwelling system where there was sufficient biological production in the surface waters to supply the necessary phosphorus for the formation of phosphorites.

In summary, our progress to date includes (1) completion of our at-sea field program, (2) construction of distribution (figure 1) and bathymetric maps, (3) preliminary data on phosphorus content, (4) preliminary elemental analysis, (5) preliminary mineralogical analysis, (6) preliminary textural analysis, and (7) preliminary paleoenvironmental interpretations. So far, we can conclude that rich phosphorite deposits are present offshore of Point Sur, Cape San Martin, and Pescadero Point. Whether these deposits will be economical to mine has not yet been determined.

Our future plans include much more detailed analysis of many more samples for their elemental composition, phosphate content, mineralogy, and diagenesis.

Publications

Mullins, H.T. and R.F. Rasch. Phosphorites offshore of Point Sur and Cape San Martin, California. Geol. Soc. Amer. Cordilleran Sect. Mtg., March, 1981. (Abstract submitted.)

Cooperating Organizations

U.S. Geological Survey, Menlo Park

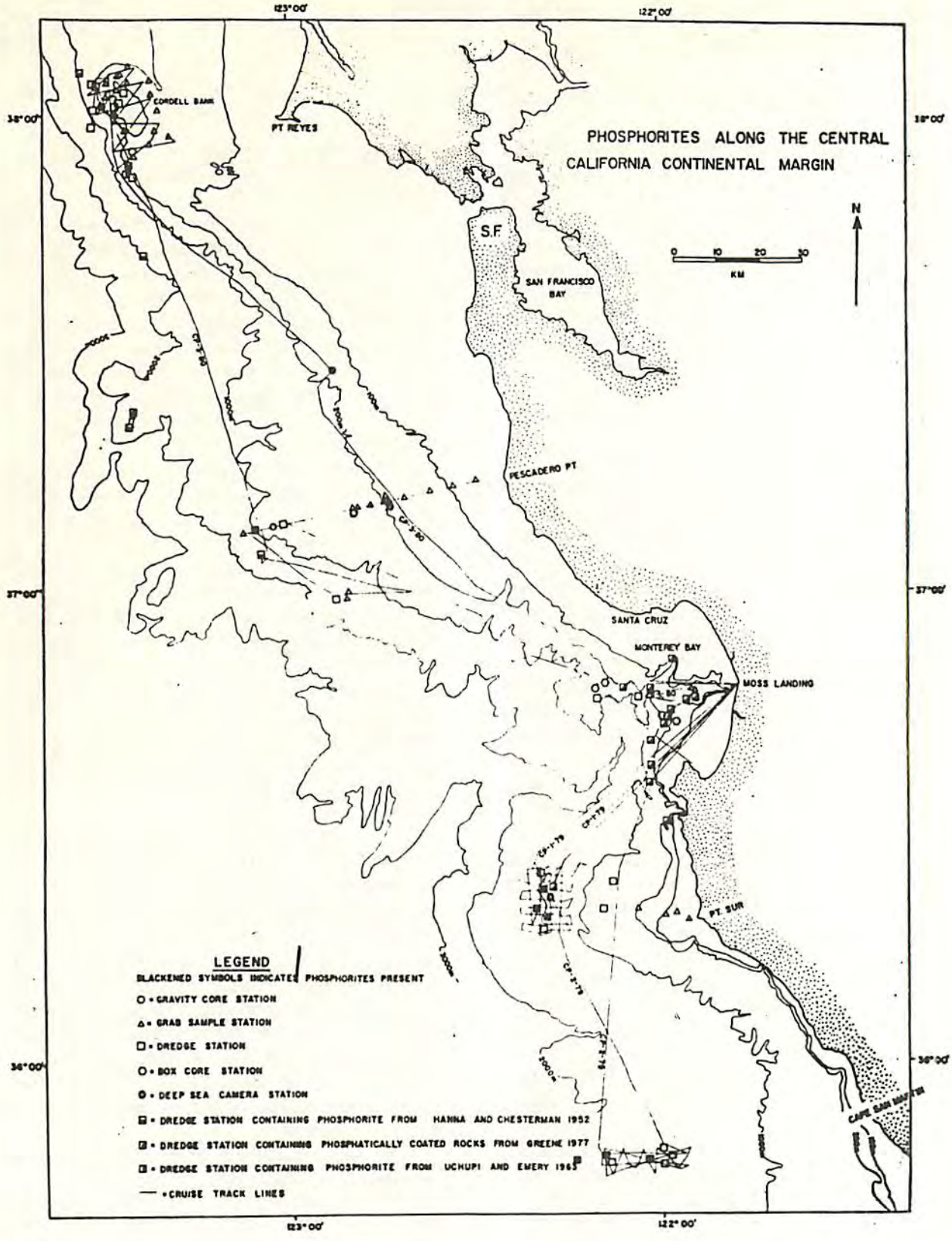
PHOSPHORITES ALONG THE CENTRAL
CALIFORNIA CONTINENTAL MARGIN
123°00'
122°00'
38°00'
37°00'
36°00'
CORDELL BANK
PT REYES
S.F.
SAN FRANCISCO BAY
PESCADERO PT
SANTA CRUZ
MONTEREY BAY
MOSS LANDING
PT SUR
CAPE SAN MARTIN
0 10 20 30
KM
N
LEGEND
BLACKENED SYMBOLS INDICATES PHOSPHORITES PRESENT
○ = GRAVITY CORE STATION
△ = GRAB SAMPLE STATION
□ = DREDGE STATION
○ = BOX CORE STATION
⊙ = DEEP SEA CAMERA STATION
▣ = DREDGE STATION CONTAINING PHOSPHORITE FROM HANNA AND CHESTERMAN 1952
▨ = DREDGE STATION CONTAINING PHOSPHATICALLY COATED ROCKS FROM GREENE 1977
▣ = DREDGE STATION CONTAINING PHOSPHORITE FROM UCHUPI AND EMERY 1965
— = CRUISE TRACK LINES

Figure 1

Coastal Governance in California, with Special Reference to State-Local Collaborative Planning

UC Berkeley
R/CZ-49
1978-79

Eugene C. Lee and Stanley Scott

The California Coastal Act of 1976 established a system of state-local collaboration in coastal zone planning. Meanwhile, the federal coastal zone management program has proceeded, encouraging a complex new federal-local-state system of coastal governance. Because of its 1976 legislation, California is ahead of most other states in the process; its developing history and past experience with coastal management have afforded excellent opportunities for learning.

This project has set out to thoroughly study coastal governance in California to determine how effective it has been and how it may be improved. A major goal has been to publish these findings for easy access by interested audiences.

The work principally comprised interviewing knowledgable individuals, and working on several manuscripts. Among the most important of the interviews were twelve two-hour sessions with Joseph Bodovitz, first Executive Director of the California Coastal Commission. These explored questions and topics raised by approximately eight such interviews conducted in 1977-78. Additional interviews dealt with other participant-observers' views and evaluations of coastal governance activities and policy, as well as changes in the process noted over time; the working of the appointment process for selecting state and regional coastal commissioners; and legislative activity on coastal bills considered in Sacramento in 1977, 1978, and 1979.

"Coastal Planning in California: A Progress Report," was published as the June-August 1978 issue of the Institute of Governmental Studies *Public Affairs Report*. Draft manuscripts were prepared of the Bodovitz interview material and of the legislative activity interviews. The legislative drafts are being revised for publication in 1981. At the same time, material on coastal recreation issues collected in 1977-78 was augmented by library research and by information obtained from coastal and other state agency offices in San Francisco and Sacramento; the results were analyzed in reading-draft manuscripts. The reading drafts have been circulated and revised for publication in 1981.

Several recent published writings on coastal policy and governance (with special reference to California) have been compiled, and some are being specially revised and updated. This collection of coastal essays, entitled *Coastal Conservation: Essays on Experiments in Governance*, was published by the Institute of Governmental Studies in 1981.

The 1978-79 project year saw a number of changes, including a good deal of negotiation and bargaining between the state Coastal Commission and local governments vis-à-vis the review process for local coastal plans, and especially the degree of stringency and specificity required. The net result appears to be an appreciable shift on the part of the Coastal Commission, and probable emergence of a somewhat improved relationship between the state and local levels. The early phases of this were described in "Coastal Planning Issues: A Consensus Report," and "Coastal Planning in California...," *Public Affairs Report*, June-August, 1978, both published by the Institute of Governmental Studies.

Other developments in the past year were a number of resignations or replacements among the state and regional coastal commissioners. Moreover, there seemed to be a growing awareness that attempts to influence appointments could perhaps be as important in affecting Coastal Commission policy as is influencing coast-related legislative efforts in Sacramento. Accordingly, various interested groups and individuals engaged in solicitation of the appointing authorities. This afforded a good opportunity to explore the workings of the appointment process, now that it has had several years to "mature." Preliminary findings suggest that the appointing authorities operate with a good deal of method in seeking commissioners who have experience, background, and interests that are relevant to the Commission's role and who affirm that they will contribute the time and effort necessary for good attendance, and for dealing with the heavy workload. The appointing authorities also seem to strive for a degree of balance and representation in commission appointments.

The 1978-79 project year coincided with the most vigorous legislative activity since passage of the basic Coastal Act in 1976. By early 1979 the Coastal Commission was under severe attack, with approximately forty bills introduced

in Sacramento, most of them to reduce its authority and jurisdiction. The Coastal Commission responded by developing its own legislative program. Moreover, conservationists rallied as they had not done since 1976. The result was some intense negotiations and passage of two omnibus bills. These got Coastal Commission support for the most part--although the support was lukewarm on some aspects of the legislation, and the commission actively opposed one or two specific provisions, e.g. the exclusion of Monterey's Cannery Row from Coastal Commission jurisdiction.

Publications planned for 1981 include a thorough review and analysis of coastal legislative activity for the years 1976 through 1980, an overview and discussion of recreation issues affecting coastal communities, and explorations of how the system of coastal governance has worked and changed over time.

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Aquaculture

Development of the Science and Technology of Crustacean Aquaculture

UC Davis
R/A-28
1978-80

Wallis H. Clark and Cadet Hand

The goal of this project is to promote the development of a diversified and economically viable crustacean aquaculture industry for California. To reach this objective, we have developed an interdisciplinary program involving all critical aspects of crustacean biology. The program is organized around six major research areas: broodstock development, endocrinology, larval biology, nutrition, engineering, and pathology.

Our recent goals have been:

1. To determine environmental, physiological, behavioral, and genetic parameters involved in reproduction of laboratory cultured decapod crustaceans
2. To examine the environmental requirements of selected crustacean species in order to establish culture procedures appropriate for larval rearing
3. To define the nutritional requirements of juvenile lobsters so as to develop effective artificial rations for decapod crustaceans
4. To elucidate endocrine factors involved in the regulation of molting in cultured decapod crustaceans in order to maximize the biological potential of growth rates
5. To understand the interactions between the biological and engineered components of crustacean husbandry techniques
6. To selectively breed stocks needed to evaluate the genetic potential and best method for improving these species
7. To investigate and develop diagnostic procedures for the diseases of our cultured crustaceans
8. To aid California's aquaculture industry in identifying and remedying problems of disease and water quality.

In order to determine the interplay of environmental, physiological, behavioral, and genetic parameters involved in crustacean reproduction, we have focused our efforts on the reproductive cycle of both lobsters and shrimp.

Photoperiod Control of Lobster Ovulation

Experimental manipulation of light and temperature regimes of adult females indicated that the onset of long-day photoperiod could trigger the ovarian processes leading to egg extrusion some four months later. We demonstrated that females could be held under short day conditions for as long as 11 months without extruding, and would then show a high extrusion rate 4 months following exposure to long days. In principle, extrusions could be scheduled throughout the year, on schedule, by photoperiod manipulation alone.

Having delayed egg extrusion by prolonging "winter" lighting even into late summer, we next asked how short a "winter" light regime would suffice before the onset of long days would trigger ovulation. To determine this, two groups of fertilized females held in the laboratory for at least a year were exposed to 60 and 120 days of 8hL:16hD. Unfortunately, few extrusions were observed over the course of the experiment. We suggest several possible reasons for the poor rate of ovulation. First, we had not fully controlled the previous seasonal cycle of the lab-held females. Also a number of the animals developed shell disease and indications of malnutrition, thus we may have had too little crustacean material in the diet (an assumption derived from some of our work with juvenile lobsters).

Although long-day photoperiod had clearly acted as a trigger for ovulation in our first experiment, a few animals still had extruded under supposedly short day length conditions. Our holding tanks had not been made completely light-tight; furthermore, lighting had been unequal in the different compartments. We accordingly rebuilt 54 compartments to be light-tight, each with its own source of light supplied through a fiber optics system from a central lamp. Photoperiod may now be precisely specified and controlled in our experimental broodstock system. An experiment involving three groups with different times of onset of long days is currently nearing completion in the rebuilt system, and the results appear again to confirm the triggering nature of the photoperiodic cue.

Interaction of Molting and Egg Extrusion in the Lobster

On another front we have continued a longitudinal study of the molt and reproductive cycles of adult females. This involves maintaining females for periods of up to two years--the duration of their natural reproductive cycle. Each week the size of each ovary is monitored

by candling, and a serum sample is taken to determine the titers of female-specific vitellogenic protein (by rocket immunoelectrophoresis) and of ecdysteroids (by radioimmunoassay). When this fundamental study is completed we should have a physiological profile of the normal interaction between molting and egg-laying which may, among other things, enable us to say why the female lobster's reproductive cycle is so long, and whether it can be successfully shortened by hormonal manipulation. Results to date include the discovery of a second protein similar in molecular weight and immunology to the primary ovarian protein. This second component is found in both ovary and serum, and its titer in the latter is usually closely related to the primary component. Usefulness of serum assay for monitoring ovarian development may depend upon the nature and significance of this second component.

Control of Egg Extrusion and Fertilization in Shrimp

We conducted preliminary studies on the hormonal control of spawning in the rock shrimp, *Sicyonia ingentis*. Initial experiments indicate that eyestalk extracts might mediate the breakdown of the germinal vesicle and release of the eggs from their surrounding matrix of follicle cells. Detailed studies of the fertilization process as well as the male and female gametes have been carried out over the last year in various species of shrimp.

Following egg extrusion in shrimp the next critical event is the cortical reaction (jelly release) of the eggs. This cortical reaction of the eggs from both *S. ingentis* and *Penaeus aztecus* has been morphologically characterized, and we have biochemically identified the jelly component produced during these reactions.

We have also made significant progress in understanding the fertilization events associated with the sperm. The acrosome of *Sicyonia ingentis* sperm has been characterized, and the acrosomal reaction has been successfully induced *in vitro* with the ionophore A23187. We have sequenced and characterized many of the events of fertilization in *S. ingentis*. Other studies have shown that *Macrobrachium rosenbergii*, the freshwater prawn, possesses gametes identical to marine species of *Palaemon*. This type of sperm has also been structurally characterized, and the events of fertilization in *M. rosenbergii* have been documented.

Spawning and Larval Rearing of Shrimp

Pandalus danae and *Sicyonia ingentis* were maintained in containerized systems to determine behavioral and other characteristics applicable to aquaculture production. The shrimp were spawned, and the resultant larvae were reared in prototype hatchery systems to determine optimum conditions for hatchery technology.

A temperature-controlled mass rearing hatchery system of 400 l has been designed and built to accommodate both species of shrimp. A larval rearing protocol has been established for the system to produce animals for continued studies.

Nutrition and Diet for the Lobster

We have made significant progress in producing an artificial diet and determining nutritional requirements for the lobster *Homarus americanus*. A requirement for lecithin in our purified diet has been shown to be related to a dietary need for phosphatidylcholine. Metabolically, the requirement for phosphatidylcholine is associated with the effective transport of cholesterol in the circulatory system.

We have also found that the inclusion of oils (triglycerides) in artificial diets significantly enhances growth. Enhanced growth rates have been correlated with dietary presence of specific polyunsaturated fatty acids that are preferentially accumulated in the muscle tissue of lobsters. Other experiments have shown that lobsters can interchange constituent fatty acids of polar and neutral lipids.

Experiments with protein levels in artificial diets have demonstrated that the protein content can be reduced from 53% to 30% without any significant reductions in growth.

Lobsters that are now 18 months old have been cultured on an artificial diet since they were two weeks old. Growth rates associated with one artificial diet indicate that market size (500 gm) should be attained within 2.4 years.

Endocrine Control of Molting in the Lobster

A study of temperature and eyestalk ablation upon molting hormone (ecdysteroid) titers in juvenile lobsters has shown a rapid elevation in the hemolymph ecdysteroid titers following ablation. These molt-induced animals have hormonal titers closely resembling those of normal animals in premolt condition. The molt cycle of ablated animals at 11°C is about twice as long as ablated animals at 20°C. In addition, the animals kept at the lower temperature had a premolt peak of hemolymph molting hormone approximately twice as high as those animals raised at the higher temperature.

We examined larval lobsters for ecdysteroid content during their first three molt cycles, and observed that larval lobsters do in fact have increasing concentrations of ecdysteroids prior to ecdysis followed by a dramatic drop in post-molt. By means of extraction with organic solvents and analysis on thin-layer chromatography plates, we have identified the larval molting hormone to be 20-hydroxyecdysone.

Density-Dependent Growth Inhibition

We completed two experiments on juvenile lobster growth with profound implications for high-density crustacean culture schemes. In the first of these experiments, relatively high levels of total ammonia and other metabolites were shown to have no adverse effect upon growth, whereas water that had passed over juveniles approximately one stage older reduced weight gain of the younger juveniles by a full 40%. However, this effect was remarkably short-acting: in juveniles two compartments downstream from the older animals the effect was reduced by one half; in juveniles four compartments downstream it was reduced by seven-eighths. Nelson et al. (1980) concluded that the effect was chemically mediated and that the substance was either very short-lived or was pulsed in its release.

The results of the second experiment suggest that the substance released by the older individuals is short-lived and is probably not self-inhibitory. The implication for crustacean aquaculture is that increased growth may be achieved, paradoxically, by *cutting down flow rates*, at least to the point where the accumulation of other metabolites begins to inhibit growth. We should now be able to utilize these results to decrease the environmental component of growth rate variance and to increase thereby the heritability of growth rate under selection.

Removal of Waste Products from Lobster Culture Systems

We have also studied the distribution and removal of growth inhibiting soluble metabolites and particulate wastes. We tested a randomized array of cells for juvenile lobsters with nine different combinations of number and size of holes in the bottom of each cell. Preliminary results indicate that holes smaller than 3/32 inch diameter were detrimental.

In an effort to reduce or eliminate the need for filtration, we installed a hydrocyclone on a culture tank. A 25 micron filter was eliminated from the system with no apparent detriment. A 5 micron filter was retained to ensure conditions comparable with other tanks. A second hydrocyclone has been designed, fabricated, and tested in the Agricultural Engineering labs. It will be installed at Bodega Bay on a table with no filters. Work on this project has suggested, however, that a hydrocyclone should also be installed at the water intake for the Bodega Marine Laboratory in addition to those on each culture system. This is being investigated further.

Analysis of data from dye studies of a lobster semi-recirculating system with submerged rotating water distributor showed a well-mixed regime below the cell trays. There was, however, some differential transfer from the cells to the region below. This strongly suggests that the primary mechanism for transfer is convection rather than diffusion. Further improvement in uniformity of water quality between cells may be possible by providing more uniform turbulence below the cells.

One closed culture system, fitted with a Rotating Biological Contactor (RBC) has been operated continuously for the past year on the Davis campus. We are collecting data to establish parameters for design of RBCs to provide very low levels of ammonia in recirculated culture water. This same system, utilizing a circular tank and a submerged, rotating water distributor with water jets directed to "scrub" the tank walls, has been operated for a period of nine months with minimal cleaning.

Hybridization of *Homarus* lobsters

We have continued to develop hybrid lobster broodstock. We have made many matings between European (*Homarus gammarus*) and American (*H. americanus*) lobsters and are growing out cohorts of their hybrid offspring. Some hybrids have become sexually mature during the past year, and we have begun to mate hybrids with one another and with both parental species in order to produce F_2 hybrid and backcross generations.

Besides rearing these offspring for future broodstock, we continually use them for other studies. Laboratory bred hybrids are preferred because of their excellent growth and survival characteristics. We have also supplied lobster juveniles to other research and commercial groups.

Biochemical Genetic Studies of Decapod Crustaceans

We continually scan leg tissues of our lobster broodstock and their progeny for electrophoretic

marker genes. These will enable us to unequivocally identify animals from several different progenies after they have been reared together. We are developing a new broodstock information retrieval system for BML's computer. This will enable us to take full advantage of electrophoretic as well as other data in selecting animals for experimental matings and other purposes.

We have begun studies of biochemical genetic variation among the aquaculturally important penaeid species of the tropical eastern Pacific. We hope to sort out the taxonomic complexity among the species of *Penaeus* in this region, and to assess their possibilities for hybridization.

Disease Diagnosis of Aquaculture Animals

We completed a preliminary study of a disease of juvenile lobsters caused by a vibrio-like bacterium. Koch's Postulates for the pathogen were satisfied. The pathogenesis of the disease appears to involve a heat-stable bacterial endotoxin.

A study of a molt death syndrome found in juvenile lobsters fed artificial diets was completed with the cooperation of several groups at BML (Bowser and Rosemark, 1980). Scanning electron microscopy showed the presence of fibrous, crystalline, calcium deposits embedded on and in the exuvial exoskeleton of animals fed an artificial ration. When soy lecithin was added to the diet, mortalities decreased, and the deposits were less common.

The hepatopancreas was shown to indicate early dietary stress. We found differences between juvenile lobsters fed brine shrimp (*Artemia* sp.), an unsatisfactory artificial ration (diet M4), and starved animals as early as 8 days into the evaluation.

We studied a microsporidian parasite found in the mosquitofish *Gambusia affinis*. This parasite, tentatively identified as a *Glugea* sp., characteristically produces a large cyst, or xenoma, which is found in the mesenteries of the abdominal cavity. We discovered the infection in mosquitofish populations from several locations in southern California. Laboratory studies have shown that the parasite may be transferred by feeding spore-contaminated food to the fish. This host-parasite relationship takes on added importance because the mosquitofish is an important part of the mosquito control effort in California, and intensive culture facilities could provide a reliable source of fish.

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Cooperating Organizations

California Department of Fish and Game
Commercial Shrimp Culture International, Port Isabel, Texas
East Carolina University, Department of Biology, North Carolina
Government of Canada Fisheries and Oceans
Kordon Inc., Hayward, California
Massachusetts State Lobster Hatchery
National Marine Fisheries Service, Galveston, Texas
Occidental College, Los Angeles
Research Institute, Charleston, South Carolina
Scripps Institution of Oceanography
South Carolina Marine Resources Research Institute
University of Arizona, Environmental Research Laboratory
University of California Cooperative Extension
Weyerhauser Company, Homestead, Florida

The following individuals also provided assistance:
Commercial fishermen Ralph Hazard, Frank Donahue, and Dale Carpenter
Seafood wholesaler Michael Wagner

Control of Reproduction in the Decapod Crustaceans

UC Riverside
R/A-29
1978-80

Prudence Talbot

Our objective in this project is to acquire an understanding of the basic mechanisms involved in decapod fertilization and, having done so, to develop methods to control fertilization in commercially important crustaceans.

The control of decapod reproduction can evolve only after we have a precise understanding of the structures involved in this complex process. Decapod crustaceans transfer sperm during copulation via a specialized structure known as the spermatophore. The spermatophore comprises sperm surrounded by acellular layers secreted by the male vas deferens. The spermatophore functions not only as a vehicle of sperm transport but protects sperm during transfer to and storage by the female. The protective property of the decapod spermatophore is probably necessary for the successful continuation of the reproductive cycle.

Past investigators of spermatophore structure have had to sacrifice the male to excise the reproductive tract. We have developed a technique to induce spermatophore extrusion from living animals by electrically stimulating the base of the fifth walking leg with 12 amps delivered through a variable transformer. We have collected spermatophores from lobsters (*Homarus americanus*) for over a year. Males may be restimulated to extrude spermatophores several times; however, we found less extrusion during the summer months. Although sperm were present in the vas deferens of these males, they had not moved into the terminal part of the vas, and thus extrusion could not be induced. Additional information on mechanisms controlling sperm transport would help overcome this problem. Otherwise the technique should be very useful in experimental and aquacultural work with lobsters.

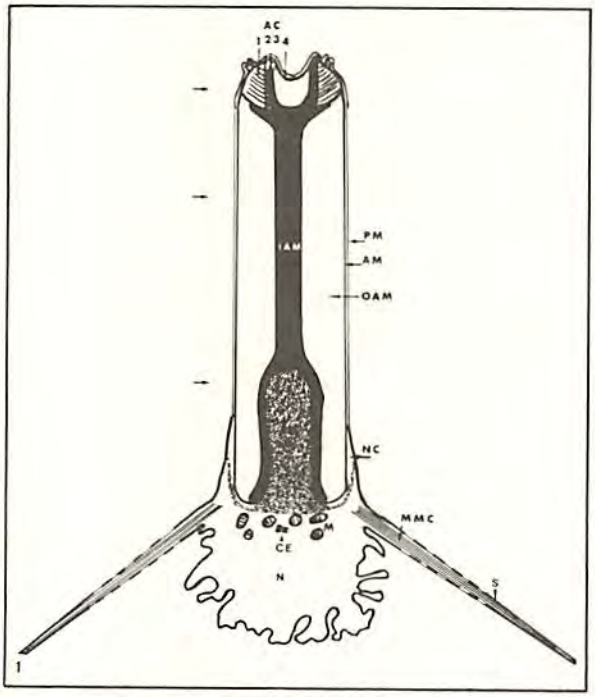

Figure 1. Schematic diagram of lobster sperm.
AC, IAM, and OAM = parts of acrosome
N = nucleus
S = spikes
Spikes are stationary, and sperm are usually non-motile.

Figure 2. Electron micrograph of a lobster sperm. (Photo by P. Talbot)

After extrusion, the spermatophores were fixed in glutaraldehyde and processed for one of three methods of examination: light microscopy or transmission or scanning electron microscopy. We analyzed the structure of lobster and crayfish (*Pacifastacus leniusculus*) spermatophores. This information will be useful in subsequent studies on sperm storage mechanisms. We have partially completed our ultrastructural studies on formation of lobster spermatophores.

Figure 3. Scanning electron micrograph through a lobster spermatophore. Sperm are present at the bottom of the micrograph. Above the sperm, the coats of the spermatophore wall and large globules are visible. (Photo by M. Kooda-Cisco)

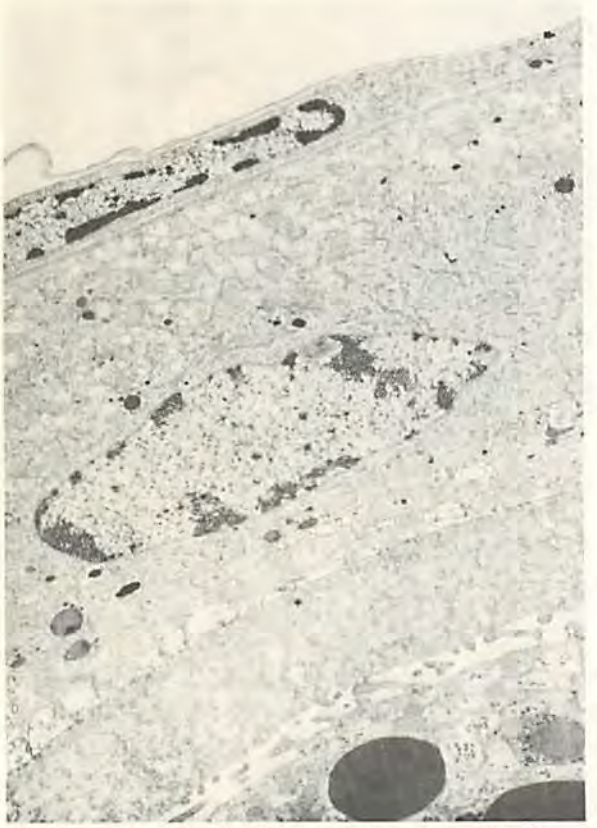

Figure 4. Transmission electron micrograph through the wall of a mature ovarian follicle. The surface of the oocyte (bottom right) is surrounded by a chorion, single layer of follicle cells, basement membrane, and surface cells. (Photo by P. Talbot)

We have made numerous attempts to freeze and thaw lobster sperm. In all cases, the acrosomes of most sperm were damaged. We have concluded that lobster sperm are exceptionally sensitive to freezing, and that cryopreservation is not a viable technique for their long-term storage. We will begin to investigate the feasibility of storing lobster sperm in a hardened spermatophore.

We are continuing our analysis of ovarian morphology using lobsters. We have collected numerous scanning electron micrographs of lobster follicles and the ovarian wall. This information is helping us understand the architecture of this complex and important organ.

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Cooperating Organizations

Bodega Marine Laboratory

Use of Thermal Effluent in the Culture of Crustacea

Jon C. Van Olst, Richard F. Ford, and James M. Carlberg

Thermal effluent has excellent potential as a source of warm seawater that can be used to accelerate growth rates and thereby reduce production costs in aquaculture.

The objectives of this project were to assess the benefits and problems involved in using thermal effluent as an economical source of heat in the culture of commercially important marine species in southern California and to develop the biological and technical information necessary for the successful culture of these species. The research concentrated on refining certain specific aspects of the culture of the American lobster, *Homarus americanus*, that are crucial to the development of a commercially viable lobster culture industry.

As a result of eight years of research we now have definitive results indicating that thermal effluent from coastal power plants can be used effectively in the culture of the American lobster. Fluctuations in effluent temperature and concentrations of major industrial pollutants, such as heavy metals and chlorinated hydrocarbons (pesticides and plasticizers), are well within acceptable limits. Furthermore, computer simulation studies show that culture procedures employing the direct use of thermal effluent are the least-cost methods of providing seawater at elevated temperature in temperate regions. The optimal culture temperature, 21°C, has been established by determining the temperatures that produce the maximum rate of growth and the best feed conversion efficiency.

Based on measurements of ammonia excretion rates and acute and chronic toxicity studies, we have determined the filtration requirements and seawater flow rates necessary to maintain this critical metabolite below acceptable limits in commercial lobster culture operations.

After rigorous testing of prototype production systems we have developed production techniques and laboratory-scale culture systems that appear to be suitable for commercial use. However, further refinement and evaluation of these systems and methods on a pilot-scale basis is required before applying them on a commerical scale.

Recent Accomplishments

Water Quality and Temperature. Previous results indicated that heavy metal concentrations in coastal seawater and thermal effluent were within acceptable limits for use in the culture of the American lobster. We have demonstrated similar results for chlorinated hydrocarbons, another class of industrial pollutants. In addition we have determined acceptable levels of ammonia, the primary toxicant produced by lobsters themselves. We also have demonstrated that fluctuations in effluent temperatures do not cause adverse or prolonged affects on growth or survival of lobsters.

Nutrition and Energetics. We determined the effects of temperature on feed conversion ratios and can now select culture temperatures that optimize both the growth rate and conversion efficiency of lobsters. We also evaluated several feed supplements and binding agents to improve diet formulation and physical properties.

Reproduction and Genetic Selection. We have cultured hybrids from *H. americanus* and *H. gammarus* crosses and evaluated the progeny for desirable culture and market traits.

Communal Rearing. Previous studies showed that using three-dimensional layers of substrate or habitats increased the carrying capacity of communal rearing tanks. Recent results indicate even higher density can be maintained if the claws of the communally-reared lobsters are immobilized.

Engineering. The results from continued testing of our "Deep Tank" system indicate that vertical sets of containers with solid bottoms require less maintenance and are less expensive to fabricate than previously developed systems. Lobsters cultured in this high-density system exhibited rates of growth equal to those found for lobsters held in the flushing tray and care-o-cell culture systems developed previously.

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Studies to Refine Hatchery and Ocean Rearing Methods for the Purple-Hinge Rock Scallop

San Diego State
R/A-31
1978-80

Charles F. Phleger and David L. Leighton

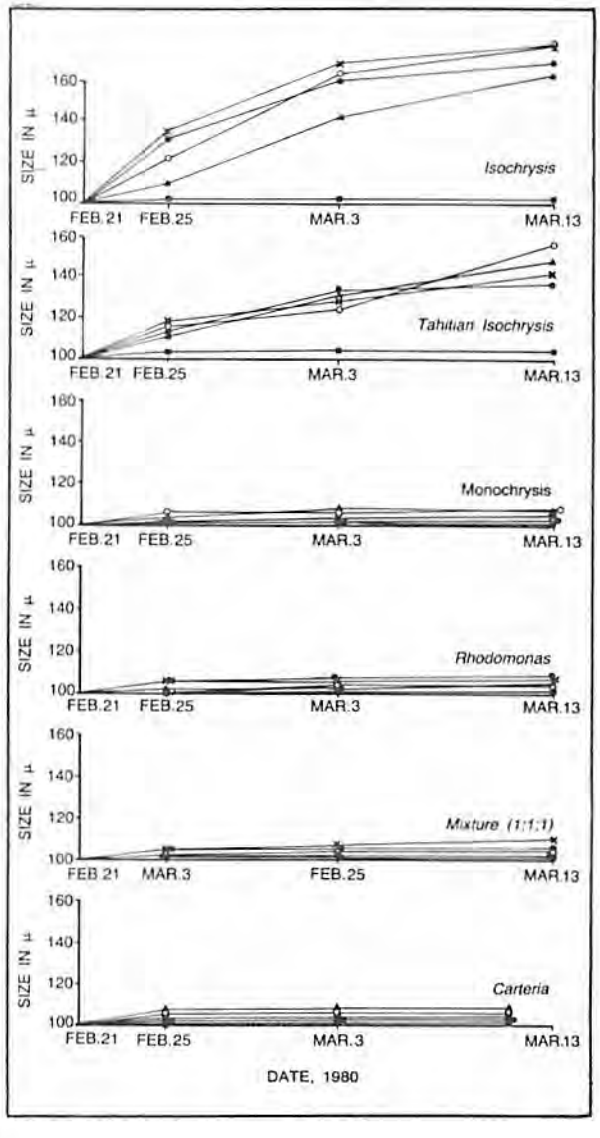
This project was undertaken to improve the "state of the art" of hatchery culture and to advance field rearing approaches for *Hinnites multirugosus*, the purple-hinge rock scallop. Our recent work centered on refinement of hatchery methods. Feeding experiments with larvae and postlarvae were performed; they yielded important information on optimal diets and feeding levels. We examined proper light and aeration for larval success and studied lower salinity limits and artificial seawater tolerance for larvae. Hyposaline conditions and use of artificial seawater may provide methods to obviate ciliate and bacterial contamination, which are important problems during early growth periods. Uptake of dissolved organic matter and particulate organic matter was demonstrated in juveniles, and seems to be an important aspect of nutrition. We perfected a plastic rearing panel for containing and rearing scallops from early juvenile to market adult size.

The six algal diets tested included *Isochrysis galbana, Monochrysis lutheri, Rhodomonas* sp., a 1:1:1 mixture of these three, a Tahitian strain of *Isochrysis*, and *Carteria pallida*. (Tahitian *Isochrysis* was supplied through the courtesy of Dr. Bob Guillard at Woods Hole Oceanographic Institution.) Most of the rock scallop larvae in these diet tests were obtained from two spawnings that were induced on February 8 and July 24, 1980. Growth of *Hinnites* larvae was significantly better with *I. galbana* and Tahitian *Isochrysis* than with the other four diets (figure 1). Feeding experiments were also performed on early larvae, prior to attainment of the straight hinge veliger stage. Tahitian *Isochrysis* gave the best growth with the lowest mortality.

A nutrition study designed to examine effects of diet on growth and survival of *Hinnites* postlarvae included the algae *Isochrysis galbana, Monochrysis lutheri, Thalassiosira pseudonana* (3H), Tahitian *Isochrysis*, and *Phaeodactylum* sp. Both *Isochrysis* and Tahitian *Isochrysis* supported best growth with no mortality at a concentration of 10^5 cells/ml. In these observations *Monochrysis* proved to be the poorest diet. High mortality occurred in almost all cases, possibly because algal metabolites detrimental to *Hinnites* were released into the medium. In earlier studies (Leighton and Phleger, 1978) *Monochrysis* cultured from another stock was a very beneficial food.

Early developmental success of *Hinnites* larvae was best in the dark without aeration. There was a more than 10% increase in growth under these conditions with least mortality, and larvae appeared most healthy and well formed. The lower lethal salinity limit for *Hinnites* larvae occurs between 16 and 19.5 ppt. Average mortality at 16 ppt was 45%, and at 19.5 ppt it was 6%. *Hinnites* larvae appear to grow and survive slightly better in artificial seawater prepared with distilled water than in filtered and UV-treated

Figure 1. Growth of *Hinnites* larvae on six different algal diets.



natural seawater. This may reflect lower populations of ciliates, major predators of larvae, and thus may be a method to avoid ciliate infestations.

We studied uptake of both dissolved and particulate organic matter by *Hinnites* juveniles to complement earlier studies of their phytoplankton nutrition . Kelp exudate was obtained *in situ* by radiolabel with $NaHC^{14}O_3$ (2 mC) and filtered through 0.22 μ millepore filters to obtain dissolved organic matter. Radiolabeled particulate matter was obtained by feeding C^{14}-kelp to abalone and collecting the feces. Rock scallops accumulate dissolved organic matter C^{14} into soft body tissues at 200 dpm/mg (dry weight) after 24 hours from a seawater medium containing 17 dpm/mg seawater. Significant uptake and assimilation occurred as label was detected in carbohydrate, free-reducing substances and RNA. Juvenile rock scallops accumulated 821 cpm/mg dry weight C^{14} 48 hours after feeding on suspended and finely particulate C^{14} abalone feces (specific activity: 1614 cpm/mg dry weight) and 450 cpm/mg dry weight after one-week exposure to radiolabeled feces. Since large populations of rock scallops may occur in and near kelp beds (*Macrocystis pyrifera*), both dissolved and particulate matter derived from the kelp may be important as additional food sources.

We designed a plastic rearing panel for containing and rearing rock scallops for bay or open-ocean culture. Briefly, the panel has a series of circular depressions in an ABS (acrilonitrile-butadiene-styrene) sheet to contain scallops. Holes are drilled in each well to facilitate cementing, and a temporary retaining mesh is glued or taped over each circular depression. After three months, the scallops cement to the well bottom, and the temporary retaining mesh can be removed. Market-size scallops can be obtained within 1.5 years from seeding the panel with juveniles. A full description of the "reusable plastic rearing panel applicable to aquaculture of the purple-hinge rock scallop" was presented to the University of California Board of Patents, and official application for patent protection was made to the United States Patent and Trademark Office.

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Cooperating Organizations

National Marine Fisheries Service, La Jolla
Scripps Institution of Oceanography

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

UC Santa Barbara
R/A-32
1978-80

Daniel E. Morse

In this project we have identified the natural biochemical triggers that normally are required to induce and control spawning, reproduction, larval settlement ("recruitment"), metamorphosis, and rapid early post-larval development and growth in the commercially valuable large red abalone (*Haliotis rufescens*). Based upon these findings, we have developed simple, safe, and inexpensive biochemical procedures to control these processes for more efficient production and reseeding of abalone and other commercially valuable shellfish. These findings now are being applied in research and development programs with more than twenty valuable food species (including abalones, oysters, scallops, mussels, and giant clams) in the United States and a number of other countries.

Control of Larval Settling, Metamorphosis, Early Development, and Survival

We recently have demonstrated that the principal causes of early mortality during intensive cultivation of abalone are microbial overgrowth, developmental retardation, and developmental abnormalities resulting from cultivation of the planktonic larvae in the absence of naturally required inducers of larval settling and metamorphosis. We have shown that the addition of γ-aminobutyric acid (GABA), the inducer we have found to be *required* for metamorphosis of *H. rufescens* larvae, can be used inexpensively, conveniently, and dependably in pure chemical form for virtually 100% effective induction of settlement, metamorphosis, and normal rapid development, with virtually complete protection against early mortality (table 1).

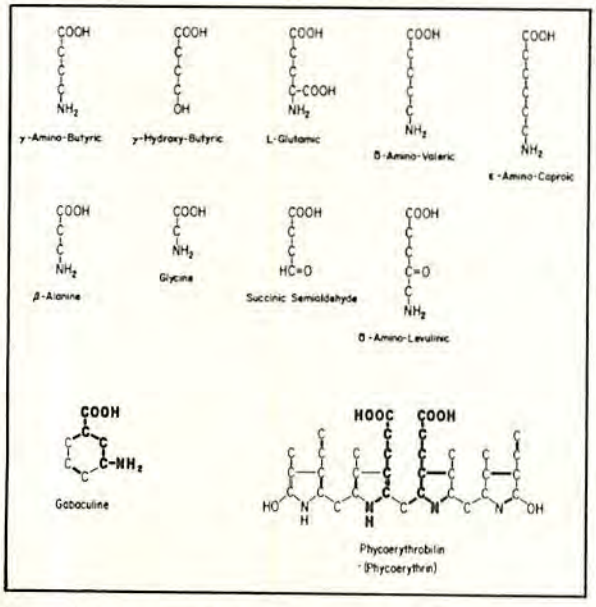

Figure 1. Compounds that induce settling of competent *H. rufescens* larvae, showing homologous relationships between active inducers. Methylene hydrogen atoms have been omitted for clarity.

Table 1
Requirements for GABA and Antibacterial Agents for Efficient Settling, Metamorphosis, and Control of Mortality

Inducer (10^{-6} M)	Antibiotic (150 ppm)	Mortality (%)	Settled (%)	Metamorphosed (%)
0	0	38	4	0
0	Pen + Strep	0	0	0
GABA	0	88	0	0
GABA	Pen + Strep	0	100	>99

Competent larvae of the red abalone (*H. rufescens*) were analyzed as described in figure 5, except that aliquots of ca. 200 veligers (10 days post-fertilization) were incubated (in 250 ml standing seawater, 15°C) in the presence or absence of GABA and the antibiotics penicillin-G and (dihydro)-streptomycin as indicated. The percentages of animals dead, viably settled on glass, and those metamorphosed (showing juvenile shell growth) were quantitated after 68 hours.

The basis for these findings was our observation that planktonic larvae of the California red abalone (*Haliotis rufescens*) normally are induced to settle and begin metamorphosis, benthic feeding, rapid development and growth by specific crustose red algae. From these natural algal inducers we were able to identify a family of homologous chemical inducers (figure 1) that can be used conveniently and inexpensively, in pure form, to induce behavioral and developmental metamorphosis of abalone larvae upon natural or synthetic substrates. Of these chemical inducers, the most potent and inexpensive is γ-aminobutyric acid (GABA), a naturally occurring amino acid and potent neurotransmitter in many species.

Larvae produced by our previously described

technique for peroxide-induction of spawning, followed by controlled fertilization and cultivation in 15°C fresh filtered seawater, become uniformly competent for GABA-induction of settling 6-7 days following fertilization (figure 2). At high concentration (10^{-3}), GABA

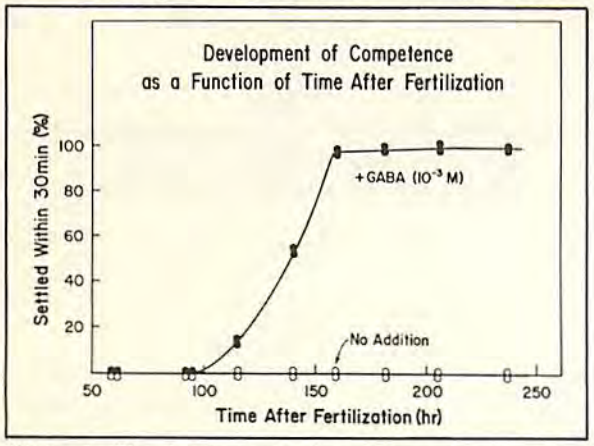

Figure 2. The development of competence for the induction of settling by GABA is followed in a population of larvae as a function of time (at 15°C) following fertilization. Aliquots of the developing larvae were withdrawn and assayed in duplicate both in the presence (filled circles) and absence (open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

induces 100% of all competent abalone larvae to settle and begin benthic locomotion and feeding behavior within minutes after its addition to seawater (figure 3). At lower concentrations

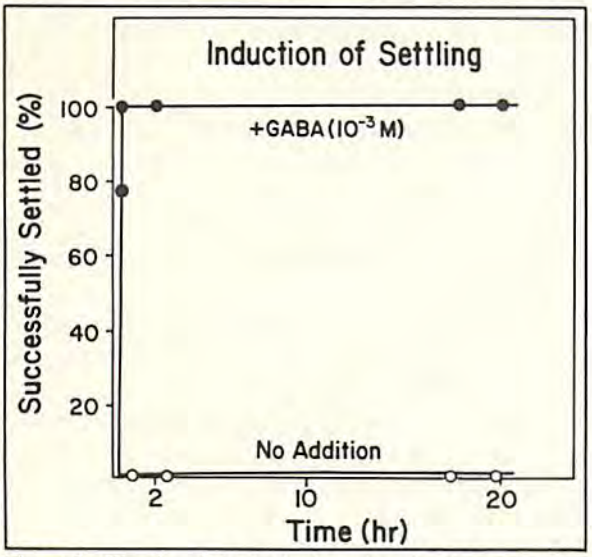

Figure 3. Kinetics of the induction of settling in a 7-day-old population of larvae. Assays were performed in duplicate, both in the presence (filled circles) and absence (open circles) of added GABA (10^{-3}M). The percentage of larvae in each vial exhibiting plantigrade attachment was quantitated by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

(10^{-6} M Optimal), induction of settling proceeds over 1-3 hours, with $\geqslant$ 95% of all competent larvae showing developmental metamorphosis to the adult form (marked by the growth of the

Figure 4. Developmental metamorphosis induced by GABA. Induction results in the synthesis of conspicuously rayed new shell, characteristic of the adult, as seen in the specimen on the right fixed in formalin 42 hr after induction by 10^{-6} M pure GABA. The sibling on the left, treated in parallel, received no GABA. Longest dimensions ca. 310 and 250 μm, respectively.

new, adult shell--see figure 4) within 2-3 days.

Use of GABA or other related naturally required biochemical inducers thus provides a convenient and inexpensive means for efficiently inducing the rapid settlement (recruitment), metamorphosis, and high survival of this species. Synchronous development with a high yield of survival thus can be achieved for intensive cultivation (and reseeding) of this protein-rich and commercially valuable food species. GABA also has been found an effective inducer of settling, behavioral, and developmental metamorphosis of the planktonic larvae of certain other species of marine molluscs; functionally related simple transmitter substances are proving useful in controlling the development of a large number of other species as well.

Development of a New Bioassay for the Sensitive and Rapid Detection of Toxic Chemical Pollutants in the Marine Environment

We have found that the GABA-dependent induction of behavioral and developmental metamorphosis of abalone larvae also can be used as a convenient "bioassay" for quantitating and defining other factors that may influence (or be required for) the success of these processes. Thus, for example, the GABA-dependent induction of settling provides a rapid bioassay (figure 5) for the presence of interfering pollutants, including a variety of halogenated organic pesticides (table 2). Results of these assays indicate that settling (and thus, reproductive success) is far more sensitive to such environmental stress than is the simple viability of the planktonic larvae (figures 6 and 7). This bioassay also has proved useful in detecting and quantitating interference with natural settling (recruitment) of abalone larvae

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

Table 2
GABA-Dependent Bioassay--Detects Sensitivity to Pesticides at Sublethal Concentrations

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

Assay of GABA-dependent settling was performed as in figure 5, in the presence or absence of added pesticides (nominal concentration = 0.1 ppm). Mortality and interference in settling were quantitated after 15 hr at 15°C. DDT = 1,1,1-trichloro-2,2-bis (p-chlorophenyl) ethane; methoxychlor = 1,1,1-trichloro-2,2-bis (p-methoxyphenyl) ethane; 2,4-D = (2, d-dichlorophenoxy) acetic acid.

caused by industrial effluents, nitrogenous wastes, and other pollutants from urban, industrial, and agricultural sources. This new bioassay thus may be useful in defining water-quality standards required for optimal hatchery and seed-production facilities; optimal sites for cost-effective reseeding of depleted coastal habitats; and marine and aquatic environmental quality assessment standards for a variety of other purposes. Accordingly, we have transferred the technology of this new bioassay to the Southern California Coastal Water

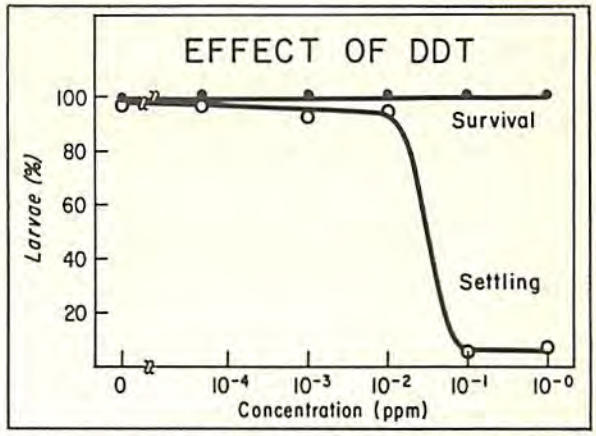

Figure 6. Sensitivity of larval abalone settling to trace-levels of the chlorinated pesticide DDT is quantitated using the bioassay technique shown in figure 5. Competent larvae were exposed to DDT for 18 hrs in the presence or absence of GABA, and effects on survival and settling were quantitated as in table 1.

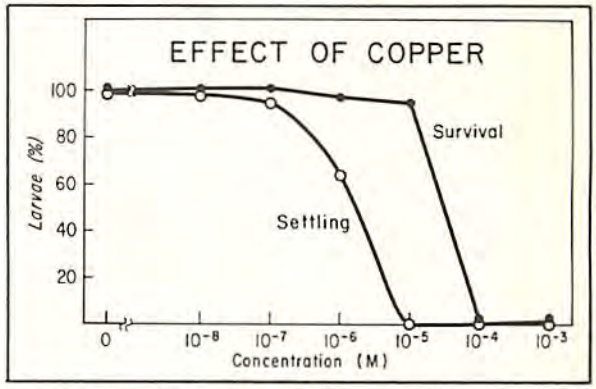

Figure 7. Sensitivity of larval abalone settling and survival to trace-levels of *copper* (cupric chloride; 18 hr exposure) is quantitated with the bioassay technique shown in figures 5 and 6.

Research Project, and to other public agencies with responsibilities for monitoring toxic chemical pollutants in California coastal waters.

Control and Acceleration of Early Development and Growth in Young Juvenile Abalones

Results of our preliminary experiments in this area suggest that the rate of growth in abalone is controlled by hormonal and ganglionic factors (in addition to food supplies, temperature, water quality, flow-rate, etc.), and that the mechanisms of this control can be analyzed and ultimately manipulated for enhancement of abalone growth rate (in much the same way that similar mechanisms controlling spawning, settling, and metamorphosis were analyzed, and convenient methods for their control developed, in our preceding research). Evidence that we have obtained with the experimentally tractable *H. rufescens* (the largest and most rapidly growing of the abalone species), using techniques we have developed for the reliable production and analysis of the young

juveniles (see below), confirms this working hypothesis.

As seen in figure 8, growth of post-larval red abalone (*H. rufescens*) can be induced by the addition of GABA (or other related, naturally required inducers). GABA thus can be used to induce active growth synchronously in large populations, making possible reliable and quantitative analysis of the requirements for regulating normal growth and for accelerating growth in this species.

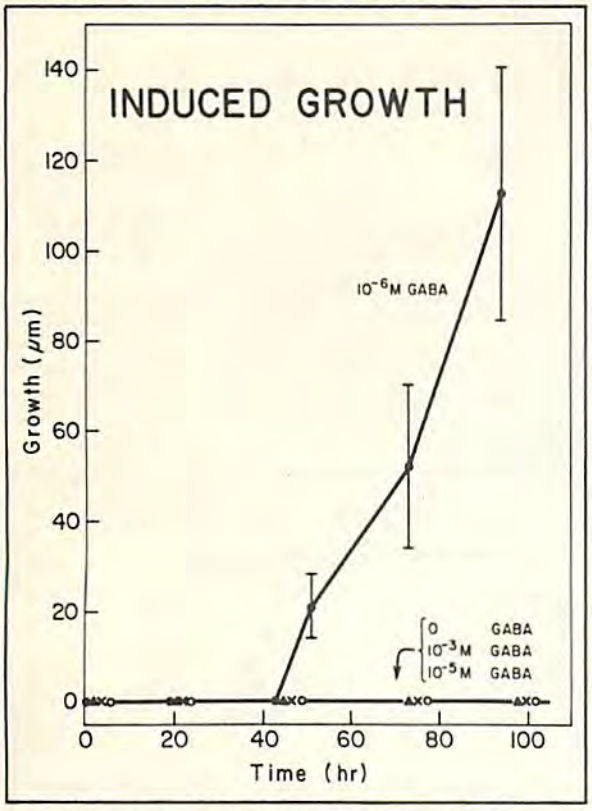

Figure 8. Induction of metamorphosis and post-larval growth in red abalone. Larvae of *H. rufescens* were produced in the laboratory and cultivated at 15° ±1°C as described previously. Seven days after fertilization, aliquots (150 ±50 larvae each) were removed and incubated, in duplicate, in the presence or absence of GABA at the concentrations indicated. Samples were examined and measured microscopically for quantitation of metamorphosis and the induction of growth as a function of time following the addition of GABA; results shown represent the means of duplicate determinations, with bars indicating the range of size of 75% of the population about the mean.

GABA at 10^{-6} M induced settling and metamorphosis in 100% of the larvae, with growth beginning synchronously ca. 45 hr after induction; the rate of growth observed is comparable to that seen for this species in other systems. Larvae incubated in the absence of GABA showed no settling, metamorphosis, or growth during the course of the experiment; GABA at 10^{-3} M induced settling (100%) with no metamorphosis or growth, and GABA at 10^{-5} M induced settling with only partial metamorphosis and no growth. Length of the shell prior to the induction of growth was ca. 250 ± 40 μm.

Results of such analyses, shown in figure 9, indicate that early post-larval growth is subject to regulation by exogenously provided hormonal factors, and that such additions may significantly accelerate early growth. Comparable results were obtained in duplicate experiments per-

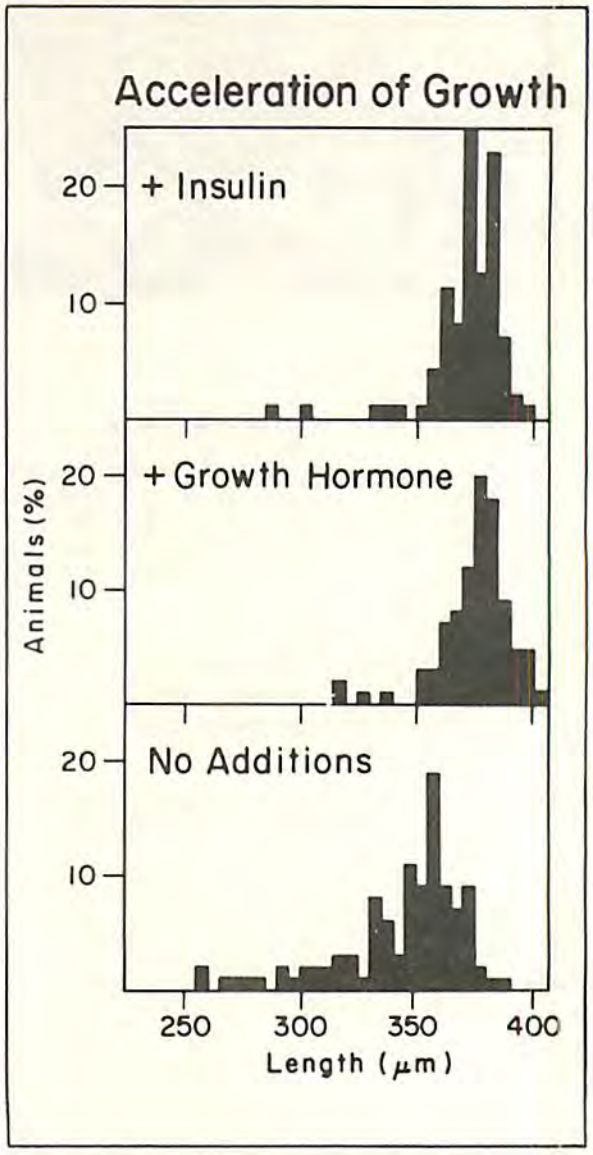

Figure 9. Acceleration of growth in red abalone. Red abalone were produced in the laboratory, and induced to undergo metamorphosis and begin synchronous growth as shown in figure 8. Aliquots of the young juveniles (150 ±50 each) were incubated in the presence or absence of various purified hormones of mammalian origin (each tested over a range of concentrations), and in the presence or absence of mixed diatoms and other microalgae provided as external food; both hormones and food were added at the time of GABA-induction of metamorphosis and post-larval growth.

Results shown are those obtained with optimal concentrations of two different exogenously provided hormones, in comparison to siblings grown in the absence of hormones, with no exogenous food. The graphs indicate the distribution of sizes determined by microscopic examination (n = 100 in each group) 4 days following metamorphosis (i.e., after ca. 2 days of growth); length prior to induction was 250 ±40 μm. Differences observed between the treated and untreated groups are statistically significant at $P < .05$. Comparable initial results also were obtained in parallel groups of siblings receiving microalgal food, as discussed in the text.

formed with or without the addition of mixed small diatoms and other microalgae (preferred food, provided in excess), suggesting that early growth rate is not limited by external supplies of nutrients, but is controlled primarily by endogenous physiological processes that regulate the efficient use of nutrients supplied either from yolk reserves or from external sources.

Results shown in figure 9 suggest also that the wide heterogeneity of size usually observed in abalone seed and adults produced with current technology is not the result of genetic variation, deficits in eggs or sperm, or inadequate nutrition (as frequently cited in the semi-popular aquaculture literature), but may instead reflect heterogeneity of hormonal activation of growth potential, which may be "corrected" by external manipulation (figure 9). We conclude that *externally provided hormonal control may be useful for accelerating early growth* (and reducing growth-rate variability) in red abalone. External manipulation of hormonal mechanisms thus may prove useful for accelerating growth, just as it has proved feasible for controlling reproduction, settling, and metamorphosis in this and other species.

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Cooperating Organizations

California Department of Fish and Game
Santa Barbara Abalone Fishermen's Association
Southern California Coastal Water Research Project
U.S. Navy, Office of Naval Research

Protective Measures against *Fusarium* Disease in Shrimp

James F. Steenbergen and Donald V. Lightner

A number of species are currently being investigated as subjects for intensive mariculture. Results with lobsters and shrimp have been most promising. Unfortunately, several diseases continue to plague crustacean mariculture, and its success or failure depends upon adequate control of disease losses.

One of the most significant problems in shrimp mariculture has been the devastating losses to outbreaks of *Fusarium* infections. This fungal disease has been reported in both wild and cultured shrimp. Mortality rates may reach 90% of infected mariculture populations, and there is no adequate prophylaxis or treatment for the disease. The usual procedure is to destroy infected populations, sterilize equipment, and begin again. Such measures are not acceptable for large-scale mariculture.

The major goals for the first year of our project were to adapt our *in vitro* phagocytosis assay for use in shrimp, and to develop techniques for preparing *Fusarium* vaccines.

Adaptation of Lobster *in vitro* Phagocytosis Assay for Use in Shrimp

Because of the very small volumes of hemolymph that can be taken from a shrimp for assay, we developed a slide technique that uses only 0.1 ml per assay. In addition, we evaluated respirometry techniques to study the encapsulation of *Fusarium macroconidia* (as contrasted to phagocytosis of the conidia).

Techniques for Preparation of *Fusarium* Vaccines

We have tested heat and formalin treatments for preparation of killed *Fusarium* vaccines. Attenuated avirulent strains of *Fusarium* have not proved effective. We have begun immunization tests with killed vaccines.

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Assessment of Sperm-Egg Interactions during Fertilization and Hybrid Formation of California Abalones

UC San Diego
R/A-39
1979-80

Victor D. Vacquier, David L. Leighton, and Cindy A. Lewis

Gametes

Haliotis rufescens spermatozoa are bullet shaped with a very large acrosome granule that contains two distinct components: a dense body at the anterior, and less dense material at the posterior (Lewis et al., 1980). When reacted, the acrosome granule releases water-soluble components (thought to be the less dense, posterior material), leaving a ghost-like sac. The extension of a 7 μm-long acrosome process occurs immediately after exocytosis of the acrosome granule, and extends through the granule ghost.

The acrosome reaction is necessary for subsequent fusion of gametes at fertilization. Acrosomes are reacted by sperm aged over several days in seawater at 4°C or accelerated by adding Ca^{2+} above the ambient 9.6 mM level (figure 1), or by adding the divalent cation ionophore A23187.

We have discovered a soluble sperm protein that is released during the acrosome reaction and appears to enzymatically dissolve the egg vitelline layer (VL) (Talbot et al., 1980). We accelerate its release by increasing the Ca^{2+} level to 300 mM. The 10,400 mw protein is separated from other proteins on the basis of solubility and molecular weight. Other highly positively charged molecules do not lyse the VL. Dissolution of the VL is our bioassay of enzyme activity (figure 2). Lysis is temperature- and concentration-dependent, and boiling stops activity. Meiosis is also activated when eggs are incubated in lysin. There is some species specificity conferred on the lysins. In one case there is no reciprocal lysis between species, and in another it is considerably retarded. Several proteolytic enzyme inhibitors have slowed but not stopped the lysin's activity. The mechanism

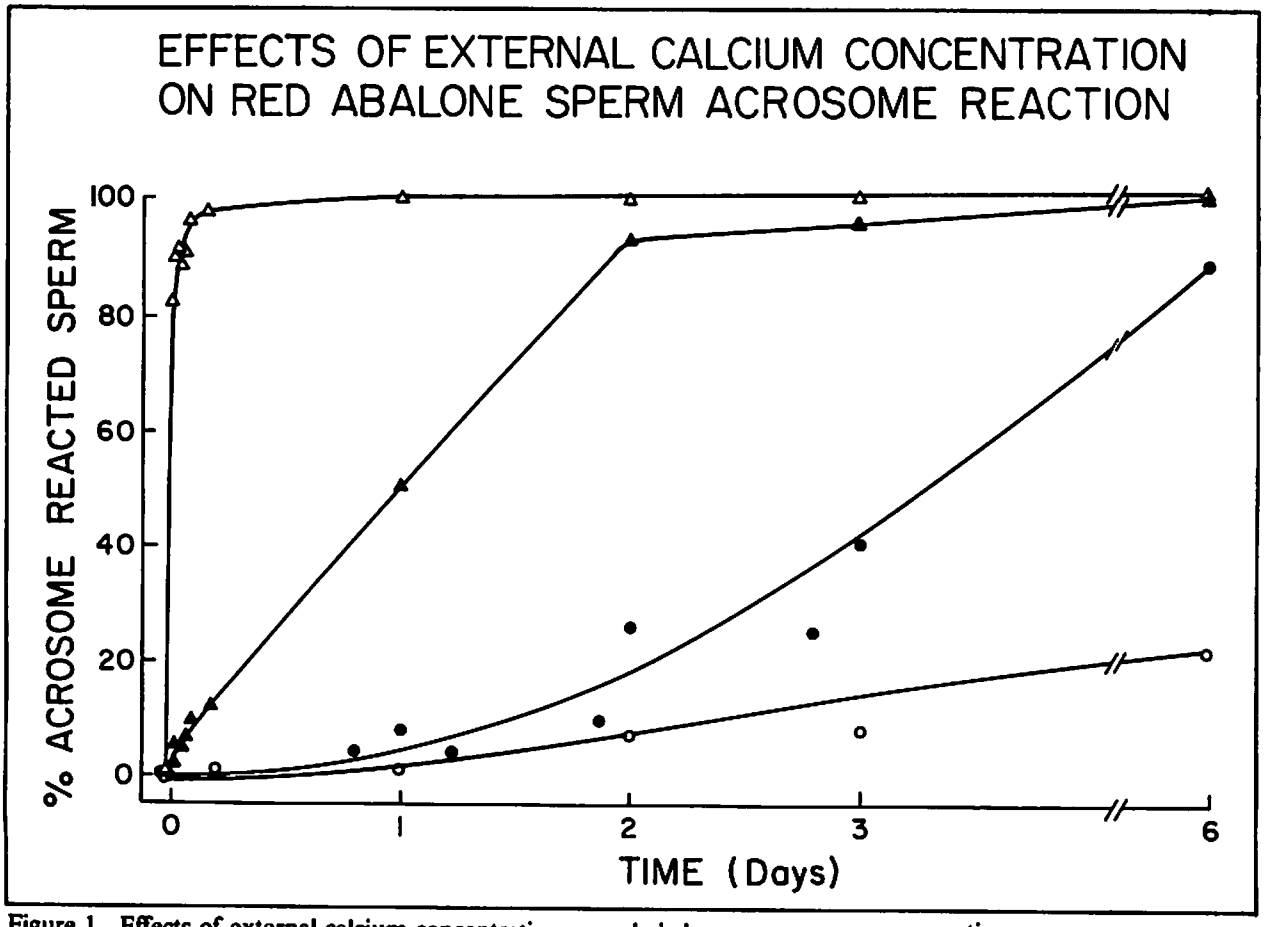

Figure 1. Effects of external calcium concentration on red abalone sperm acrosome reaction.

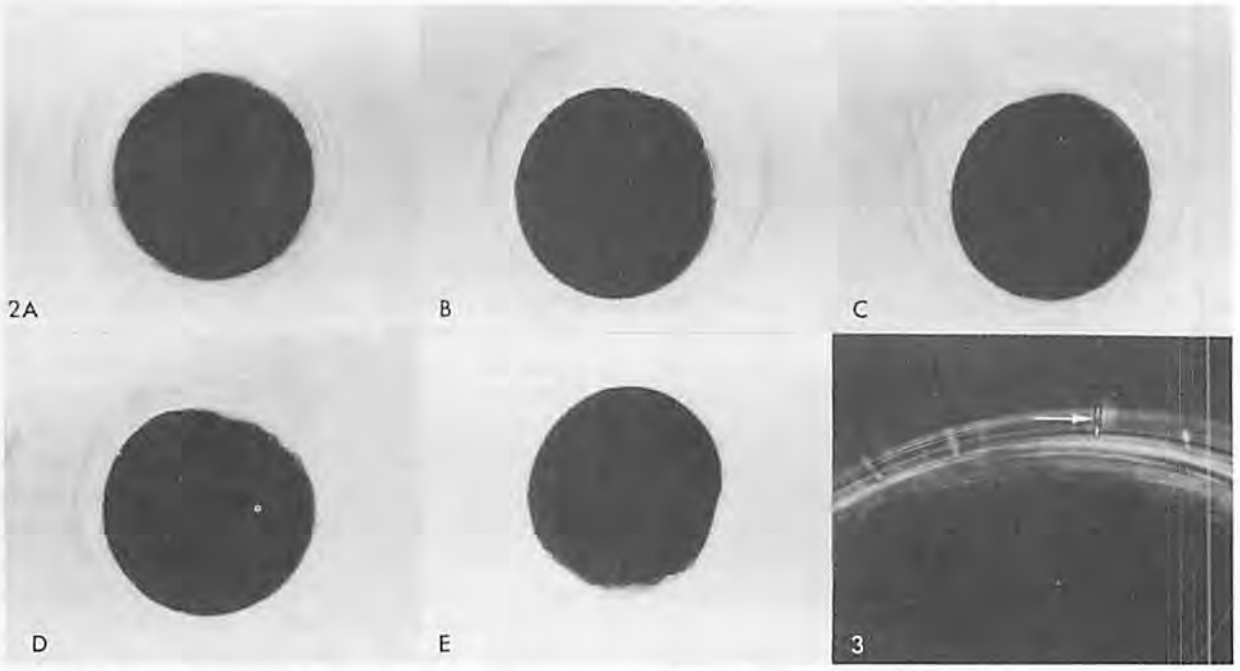

Figure 2A-E. x440. Digestion of *Haliotis rufescens* vitelline layer by *H. rufescens* sperm vitelline layer lysin.
A. No lysin present, vitelline layer intact.
B-E. Lysin added:
B. 1 minute, vitelline layer expanded.
C. 2 minutes, vitelline layer crenulated.
D. 3 minutes, vitelline layer thin and disappearing.
E. 5 minutes, vitelline layer gone.

of action of lysin is not known.

Haliotis rufescens eggs are 170 μm in diameter, surrounded by a 210 μm diameter VL and a 150 μm-thick jelly coat. The jelly expands to this size by 30 minutes after spawning. The 0.7 μm-thick VL is glycoprotein, and when lysed does not break into small molecules. Only abalone sperm lysin, protease, and ETOH have been shown to dissolve VLs.

Sperm-Egg Interaction

The first sperm contacting the VL acrosome react and enter the VL up to two minutes after sperm addition. Other sperm are reversibly bound (not acrosome reacted) at the VL (figure 3). They seem to be attached to the VL, flagella beating a vigorous figure-eight pattern, but may swim away. The sperm that cross the VL continue to swim across the perivitelline space and may contact the oolemma. Only the first sperm making contact fuses with the egg. Other sperm may contact and bind to the oolemma by their acrosome filaments, but they do not fuse with the egg (figure 4). Unfused sperm have been witnessed swimming inside the VL up to 12 hours after fertilization.

The optimum production of *H. rufescens* lar-

Figure 3. x1800. *H. rufescens* sperm (arrow) bound temporarily to *H. rufescens* egg vitelline layer. Flagellum is beating vigorously.

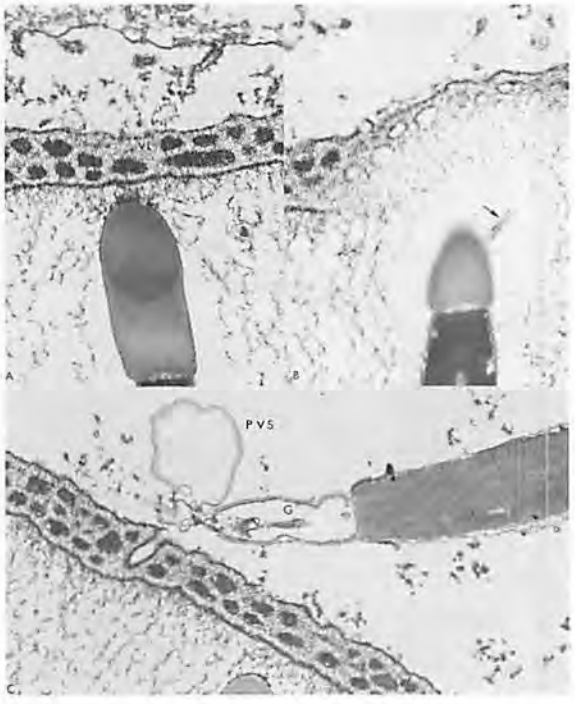

Figure 4. *H. rufescens* gamete interaction.
A. x30,600. Sperm in egg jelly (J) bound to outer surface of vitelline layer (VL). Sperm are not acrosome reacted.
B. x30,250. Sperm (oblique section) apparently undergoing the acrosome reaction (note acrosome filament, arrow). Egg vitelline layer is lysing.
C. x27,200. Acrosome reacted sperm that has traversed the vitelline layer and lies in the perivitelline space (PVS). Acrosome granule has lost its content and is a ghost (G).

vae is accomplished by adding 10^5 to 10^6 sperm per ml of eggs suspension (figure 5). Above

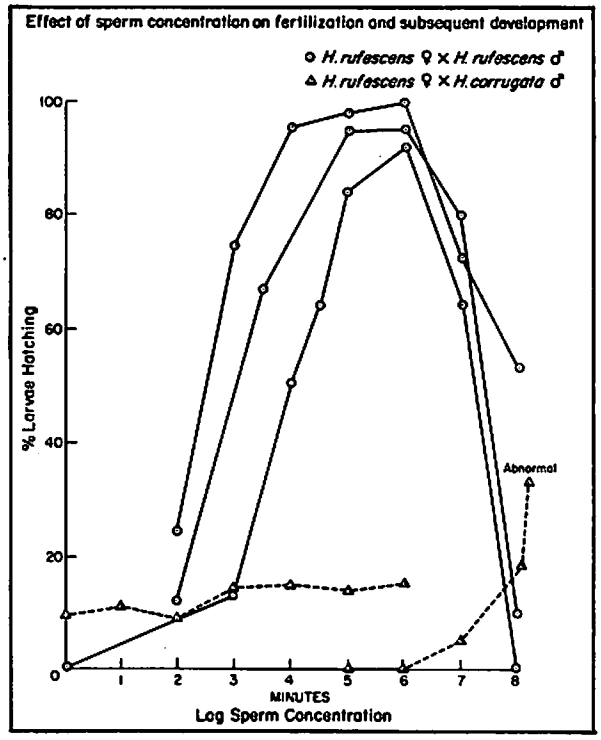

Figure 5

10^6 sperm per ml, the percent of abnormal development increases. Egg fertilizability decreases drastically one hour after spawning (*H.r.* x *H.r.*) (figure 6).

Heterologous sperm traverse the *H. rufescens* egg jelly easily and attach to the VL, but very few enter the VL. The VL, probably a mechanical block to normal polyspermy, may also block heterospecific sperm entry. Up to two minutes after addition of heterospecific sperm, *H. rufescens* sperm still enter the VL.

We have tried two approaches to increase hybrid development: (1) *H. rufescens* egg VLs are partially lysed or removed with *H. rufescens* sperm lysin. Heterologous sperm are added but do not acrosome react or bind. If Ca^{2+} levels are increased after sperm are added, some acrosomes react on the VL, in jelly or a few on the oolemma. Polar bodies form, but there is no further development. (2) When we increase the heterologous sperm concentration up to about 10^8 sperm per ml, hybrid formation increases (figure 5). We have produced up to 25% normal hybrid larvae. Heterologous lysin is not as effective on VL lysis as homologous lysin. It is likely that a critical number of sperm must be present to release sufficient heterologous lysin for sperm penetration. Hybrid fertilization must also occur soon after spawning (figure 6).

Our *H. rufescens* (female) x *H. sorenseni* (male) hybrids are 7.76 mm ± 1.60 mm in greatest shell diameter (N = 14) after 6.5 months at 15-20°C. The *H. sorenseni* controls average 7.35 mm, and *H. rufescens* controls average 10.29 mm. Thus, in this case, hybrid growth rates are approximately equal to those of the slower-growing parent. Hybrid progeny will be studied through next year.

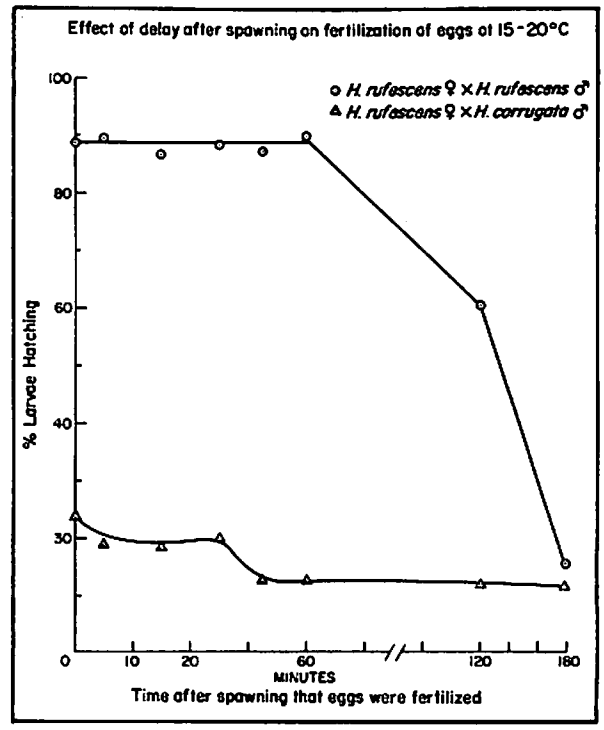

Figure 6

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Toward Seawater-Based Crop Production

UC Davis
R/A-22
1978-79

Emanuel Epstein

Paradoxically, salt inhibits the growth of crops on a larger scale than does any other substance in their environment, yet much of the globe's plant life thrives in highly saline media--in the oceans, along their shores, in estuaries, deltas, salt marshes, and saline soils. The present project is based on this paradox, which at once leads to a conclusion and poses a challenge. The conclusion is that no fundamental biological incompatibility exists between salinity and plant life. And the challenge is to develop plants that combine economic utility with salt tolerance. If successful, this approach would make it possible to use resources now useless for crop production--seawater and the mineral plant nutrients in solution in it; the approximately 33,000 km (21,000 miles) of coastal deserts; and the solar energy incident upon this vast area.

This report deals with three crops: barley, wheat, and tomato. For the grains, appreciable genetic variability in respect to salt tolerance was uncovered *within* each species. Intraspecific selection was therefore the method chosen. Intraspecific variability in the tomato appeared less promising; in this case, therefore, exotic germplasm was used to breed salt tolerance into the commercial species. *Lycopersicon cheesmanii* from the Galapagos Islands, though commercially useless, has the two features required: it is highly salt tolerant, surviving even at 100% seawater salinity, and it can readily be crossed with the commercially useful *L. esculentum* "Walters."

Experiments and results

Barley. Selections of barley, *Hordeum vulgare*, had been made in salinized solution cultures during the previous project. The best selections were grown at Bodega Marine Laboratory under irrigation with fresh water (control), 0.33, 0.66, and undiluted seawater. Nitrate and phosphate fertilizers were applied.

Barley grain harvested from this first field trial at Bodega Marine Laboratory was chemically tested for feed quality and found to be satisfactory. Irrigation with undiluted seawater caused no unfavorable changes in the chief quality factors of the grain, 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%) is so low that it poses no problems. A laboratory test for digestibility was also satisfactory. Eventually it will be necessary to conduct actual feeding trials, when adequate amounts of seawater-grown grain become available. Present facilities are inadequate for such large-scale tests.

In a second 1976-77 field test at Bodega Marine Laboratory, one line of barley gave a higher yield than previous top yields in undiluted seawater culture, approaching the average world yield of barley (estimated for 1975 to have been 1,710 kg/ha, or 1,527 lbs/acre). The test was especially significant because the season was dry, resulting in minimal dilution of the saline irrigation water. It is concluded that with further 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 lines contained in the world collection of barley--a huge reservoir of genetic diversity.

During the subsequent two seasons (1977-1978, 1978-1979) the climate returned to a normal, high-rainfall pattern, which prevented controlled irrigation during the normal season. The plantings were delayed until most of the normal rainfall had passed. This greatly shortened the growing season, and substantially reduced yields below those of the previous seasons. Further experimentation at this site will require some form of protection from rain so that the crops can be grown during their normal season, without dilution of the saline irrigation water.

In a series of irrigation trials it has been determined that it is preferable at this stage to provide a small amount of fresh water during seedling establishment, before beginning irrigation with saline water. Once the seedlings have two to three leaves, it is possible to begin a stepwise salinization of the irrigation water up to undiluted seawater.

The variability of test performance among the many cultivars and strains of barley suggested that a breeding program could be established. Some estimate of heritability for the trait of salt tolerance had to be determined. To do so, the most successful strain was crossed with the least successful. The resulting third and fourth generation progeny lines were tested for seed yield when salinity stress was imposed during the vegetative and reproductive stages of the life cycle. Yield under salt stress was demon-

strated to be a quantitative, heritable trait (h = 0.58). This estimate appears high enough for plant breeders to incorporate the character of salt tolerance into the type of barley normally used for production.

Wheat. The choice of wheat for this investigation was dictated by the facts that (1) it has the highest economic standing among the cereals; (2) it has the reputation of at least moderate tolerance of salinity (therefore giving a high probability of success); and (3) there are ample sources of genetic diversity available for exploitation.

To evaluate the extent of salt-resistant germplasm presently available, a representative number of hexaploid wheats from the world collection was screened at the maximum stress that allowed plants to survive. From over 5,000 accessions, we isolated 29 lines of salt-resistant wheat that could complete their life cycles at a salinity of 50% seawater in solution culture. Several of these selections were tested against the most salt-resistant cultivars available: "Anza," which yields well in the saline situations of California'a Imperial and San Joaquin Valleys, and "Kharchia," an Indian variety noted for its salt-resistance. The testing was done in salinized solution culture; the relative yield data are shown in table 1. The resistant experimental selections outperformed the salt-resistant cultivars in all salt treatments. This is encouraging, particularly since the lines have only been through two selection cycles. Further screening should improve these results.

Table 1
Biomass Production of Wheat Lines in Saline Solution Culture

Testing lines	Salinity (% seawater) Control	20	40	60
	% control			
'Anza'	100	28.5	5.3	3.7
'Kharchia'	100	26.3	7.3	5.9
Resistant selections	100	33.0	9.4	6.4

Field testing attempts at the Bodega Bay site have been less than satisfactory because of the high rainfall already discussed (see "Barley"). Therefore, no reliable yield data are available from these field tests. Of interest, however, is the fact that a few individual plants survived to set seed despite growth under irrigation with undiluted seawater.

Physiological studies compared a salt-resistant selection with a salt-sensitive selection under salt stress. These studies have indicated that no substantial differences exist between the lines with regard to (1) salt accumulation or translocation, and (2) response to water stress. Rather, the major differences between these lines seem to be: (1) the sensitive line has a lower rate of photosynthesis under salt stress because of a higher mesophyll resistance to CO_2 assimilation (reflecting metabolic toxicity), and (2) the sensitive line is more sensitive to the specific ions involved in the salt stress. These results have increased our understanding of the physiological basis of salt-resistance in wheat. Continued studies may yield physiological "markers" to help identify salt-resistant germplasm.

Further selection of the salt-resistant accessions already identified, combined with a breeding program, should yield superior wheat cultivars for use in coastal or inland areas where salinity is a major problem--or opportunity.

Tomato. Analyses of the data collected during the 1976-1979 greenhouse experiments at Bodega Marine Laboratory demonstrated and confirmed that salt tolerance in tomato is genetically controlled, and that this tolerance can be transferred to a useful domestic tomato variety.

Initial and successive crosses between a useless, wild, salt-tolerant tomato--*Lycopersicon cheesmanii Lycopersicon cheesmanii* -- and a sensitive domestic variety -- *L. esculentum* "Walters"--produced salt-tolerant hybrids that improved in size and quality with each successive backcross to the domestic parent.

Each generation was selected for salt tolerance at the germination and seedling stages, by continuous exposure to 40-50% seawater salinity. These same plants were then grown at the Bodega Bay site while being irrigated with up to 70% seawater. These methods successfully retained a high degree of salt tolerance, as is reflected in table 2, which gives relative survival data for the parents and successive crosses. A graphic comparison of fruit produced is given in figure 1. An additional benefit of breeding for, and exposure to, saline environments has been improved flavor of the selected hybrids when compared with the domestic variety controls.

Physiological studies performed at Davis provided information on a number of subjects pertinent to evaluating salinity tolerance.

Experiments involving the distribution and concentrations of sodium and potassium within various tissues were essential in examining plant survival strategies in saline environments. Comparative studies using the tolerant *L. cheesmanii* species and the sensitive cultivar

Table 2
Relative Plant Survival of the Wild and Domestic Tomato Parents and Selected Hybrids at Various Salinities

Testing lines	Salinity (% seawater) Control	30	50	70
	% control			
Domestic parent	100	92	46	0
F_2	100	100	83	67
BC_1	100	100	78	45
BC_2	100	75	100	40
Wild parent	100	100	100	80

(Data taken from the Bodega Field Experiments)

"Walters" showed that while neither species absorbed sodium via metabolically active transport mechanisms, the wild, tolerant line did take up high concentrations of sodium in the leaf tissue, with a minimum of detrimental effects. The sensitive "Walters" excluded sodium from the leaves, where even small amounts proved to be highly toxic. This latter strategy of salt exclusion was successful only when low salt concentrations were encountered or the exposure was for a short period. If either of these parameters was exceeded, the exclusion mechanism failed, and the plants did not survive.

From these and other studies, we have developed methods for screening for salt tolerance. They include the actual methods used to evaluate the material in the Bodega Bay studies, and tests for tissue salt concentration after exposure to a saline medium.

Conclusion

Seawater culture of crops poses an extreme challenge. The total salinity of seawater is 35,000 ppm, or a specific electrical conductivity of 4.63 mmhos/cm. Irrigation water of even 10% salinity is considered very poor.

On the other hand, use of seawater in the manner proposed in this project, and adopted in these experiments, avoids certain difficulties encountered in conventional soils. Drainage in coastal sand is excellent; the water applied readily drains back into the sea. Adsorption of sodium and other cations by the solid matrix is slight, because the cation exchange capacity of the sand is very low, and little organic matter is present. The climate at the experimental site is not extremely hot or dry. (Fortunately, similar situations exist elsewhere, as for example in certain coastal desert areas.)

The world food and energy situation is serious, and likely to become critical in the future. It was the purpose of this project to tap resources--both material and energetic--which are presently useless for crop production.

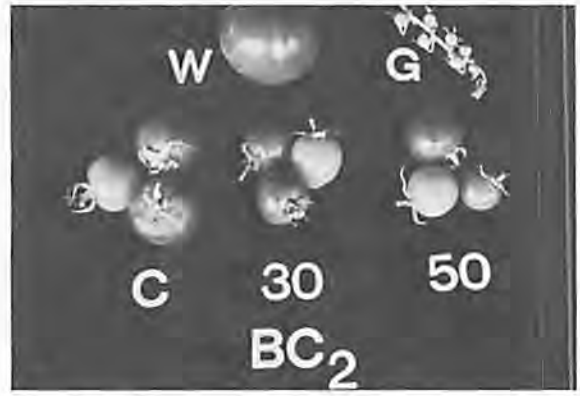

Figure 1. Tomatoes from the domestic parent (W), the wild parent (G), and representatives from the second backcross to the domestic parent (BC) taken from plants grown in fresh water (C), 30% seawater (30), and 50% seawater (50).

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* Does not include abstracts or titles published in conjunction with presentations at conferences and meetings during the period of this project.

Cooperating Organizations

Bodega Marine Laboratory, Bodega Bay, California

Dean's Office, College of Agricultural and Environmental Sciences, University of California, Davis

International Plant Research Institute, San Carlos, California

Aquaculture of Red Algae

Stanford
R/A-34
1978-80

Isabella A. Abbott and Judith E. Hansen

The biomedical uses of phycocolloids from red algae have increased in the United States. New and stable sources of seaweeds producing carrageenans and agar are needed (Neish, 1976). Specifically, the uses of microbiological-grade agar has risen dramatically, and so has its cost, reflecting the unstable foreign sources. Concurrently, it was demonstrated that Pacific Coast algal resources (e.g. *Rhodoglossum*) produce k-carrageenan suitable for use as an agar substitute (Abbott and Chapman, in press). The use and applications of agar and the highly purified agarose have spiraled in health-related fields for methods and techniques in electrophoresis, chromatography, immunology, and microbiology. The manufacturing and marketing of seaweed phycocolloids are well established. The key problems lie in manipulating the biology of the plants in order to control raw material quantity and quality. A solution lies in the development of mariculture procedures based on a solid foundation of biological parameters (Neish, 1976; NOAA Aquaculture Plan, 1977).

The goal of this project was to study the basic biology and to assess the potential of local red seaweed resources: *Rhodoglossum affine*-carrageenan as an agar substitute and *Gelidium coulteri* for biomedical-grade agar.

In this project we focused on field, laboratory, and culture studies.

Field Studies

The objectives of the field experiments were (1) to determine the local, inter-population plasticity in algal growth and colloid yield/properties, and (2) to assess colloid degradation (in terms of media-making properties) in experimental "drift crops" of the species under study.

The results show that wild crops of both species have low biomass compared to commercially harvested red seaweeds (e.g. *Chondrus crispus*). Standing crops of *R. affine* show no significant seasonal fluctuations (figure 1), whereas crops of *G. coulteri* vary seasonally (figure 2). The *Gelidium* populations studied are dominated by the tetrasporangial stage similar to other *Gelidium* species (Johnstone and Feeney, 1944) and *Iridaea cordata* (Hansen and Doyle, 1976). The effect of harvesting on *Rhodoglossum* and *Gelidium* regrowth varies between populations. When crops are harvested at the

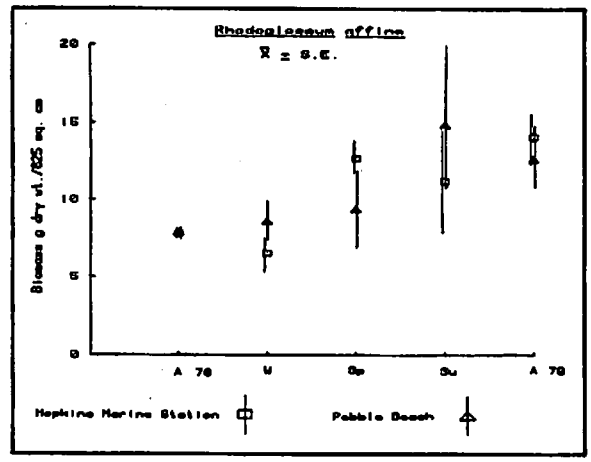

Figure 1

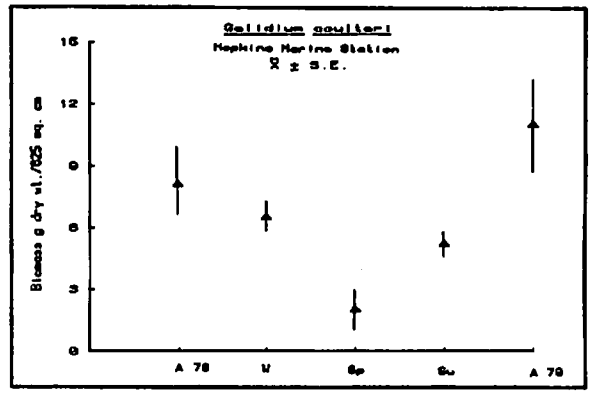

Figure 2

beginning of any season at Hopkins Marine Station (HMS), population regrowth is nearly equal, or equal to control levels within three months. At another study site (Stillwater Cove), three-month regrowth is less than control levels for both species.

The colloids from the species studied show different seasonal patterns. Kappa-carrageenan from *R. affine* shows little seasonal variation in yield or gel strength ($\bar{X}$ = 302 g/cm^2; 1.5% sol.) (Abbott and Chapman, 1980). *Gelidium* agar varies considerably in gel strength between study sites and among seasons (figure 3). Despite these variations, *Gelidium* agar and *Rhodoglossum* k-carrageenan (with modifications) perform similarly to commercial agars as microbiological growth media.

To evaluate the use of colloids from beach drift, decomposition of *Rhodoglossum and Gelidium* in artificial "drift bags" was monitored for 3.5 months. Carrageenan yield from *Rhodoglossum* showed best yield after 19 days on the beach, but best colloid for media was produced after 52 days in the drift. Agar from *Gelidium*

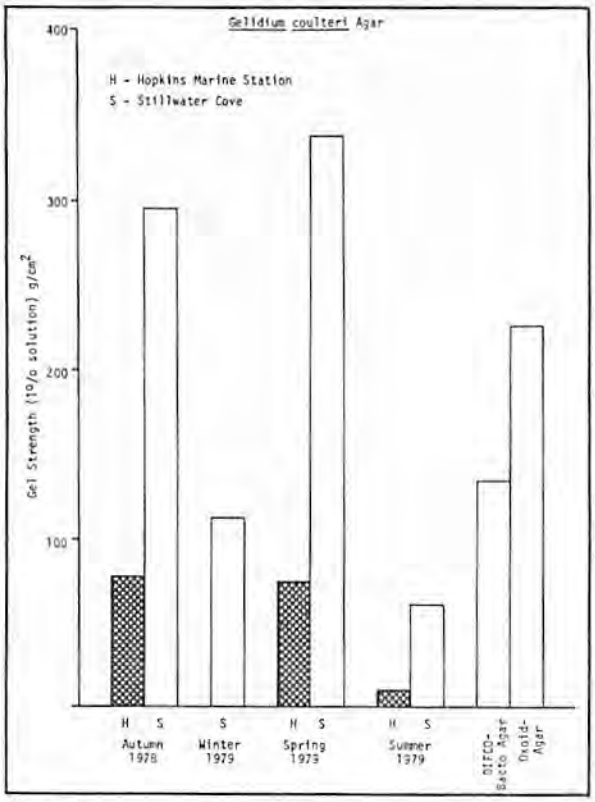

Figure 3

showed greatest yield after 35-50 days on the beach, but best agar for media purposes was produced after 19-35 days on the beach. In most cases, the *Gelidium* agar and *Rhodoglossum* k-carrageenan (with modification) were comparable to commercial Bacto-agar (DIFCO).

Laboratory Studies

The objectives of the laboratory experiments were to (1) determine the effects of irradiance levels on the photosynthetic responses of both species in air and in water; (2) to determine the effects of temperature on photosynthesis in air, and submerged; and (3) to evaluate the short-term effects of temperature shock and recovery on both species.

The results for whole plants indicate that net photosynthesis of both species at 15°C is saturated at fairly low irradiance levels 21 x 10^{15} quanta/cm^2/sec characteristics of related red algal species and higher shade plants. The peak photosynthetic rate of *Gelidium* is approximately one-third greater than that for *Rhodoglossum*. *Rhodoglossum* photosynthesis is inhibited at temperatures greater than 25 °C and less than 10°C (figure 4). *Gelidium* photosynthesis is not inhibited until temperatures exceed 32°C or fall below 10°C (figure 5). Both species show a broad tolerance to air temperature; however, the net photosynthetic rate is only one-fourth of the submerged rate.

Short-term temperature shock treatments

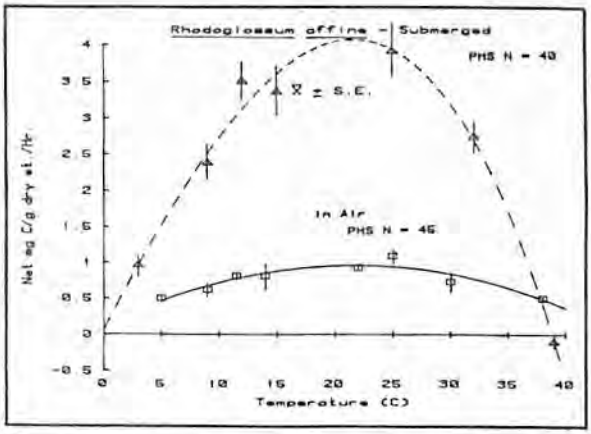

Figure 4

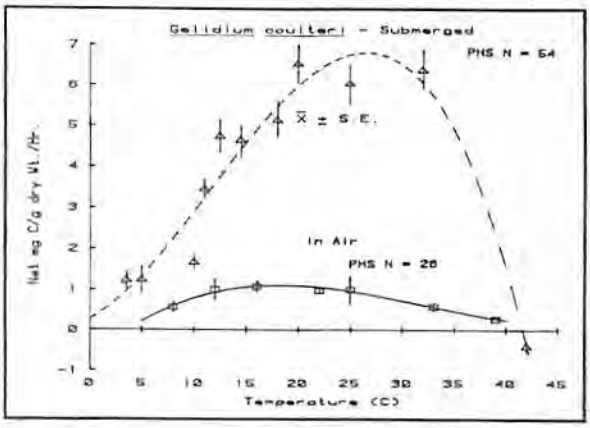

Figure 5

(10 min) to apical tips of plants corroborated the above results for whole plants and more closely defined the tolerance range of the species, in terms of photosynthetic recovery, to seawater temperature (figure 6).

The short-term production results were tested by culturing whole plants of both species at high temperatures: 17, 22, 27, and 32°C. The test *Rhodoglossum* populations died within seven days at 32°C and showed variable growth responses at lower temperatures. Following an acclimation period, *Gelidium* grew equally well at all test temperatures, including 32°C. *Gelidium* is physiologically a more flexible plant than *Rhodoglossum* and could be cultivated under a wide range of physical conditions.

Mariculture Studies

Small-scale, outdoor tank culture was used to determine stocking densities of the algal species for optimal production. Cultivation experiments were carried out for nine months. Specific growth rates for *Gelidium* of about 2.5%/day could be expected from initial stocking densities between 2-3 kg wet wt/m^2. The production results calculated from these data indicate an overall estimated maximum of 17 g dry wt/m^2/day (figure 7). Culturing results for *Rhodoglossum* were highly variable with season.

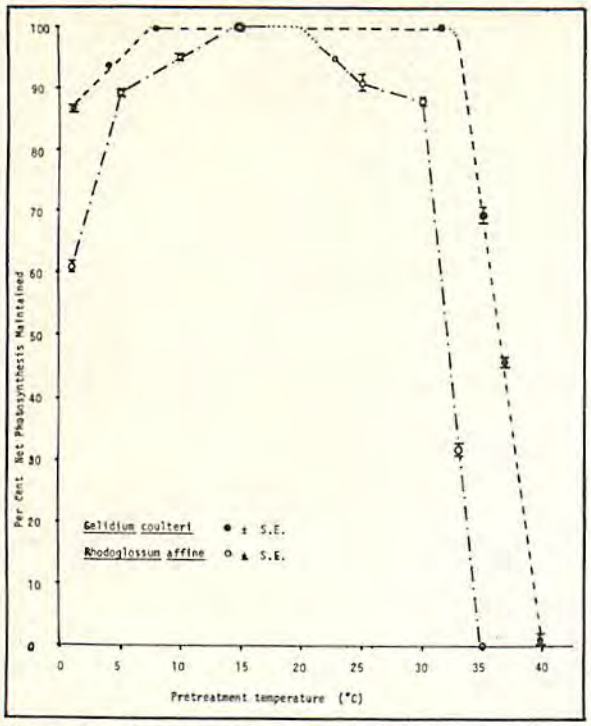

Figure 6. Photosynthetic recovery following ten-minute temperature shock treatments.

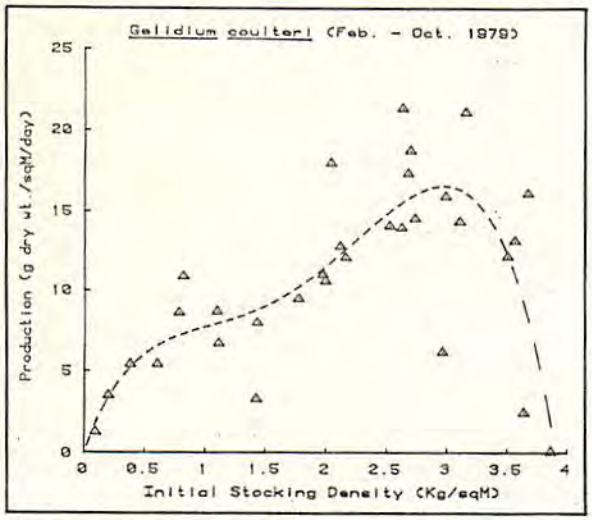

Figure 7

However, a maximum production rate is estimated to be between 12-30 g dry wt/m^2/day, with a specific growth rate of 2-3%/day at a stocking density of 3.5 kg wet wt/m^2.

Conclusions

Production of unattached *Rhodoglossum* and *Gelidium* in tank culture under ambient physical conditions (characteristic of central California) can be 4-10 times that *in situ*. Comparisons of field, tank, and laboratory-derived productivity of these plants suggest that production can be increased even more by proper manipulation of culture conditions. Net photosynthesis for these species is saturated at relatively low irradiance levels, thus allowing considerable flexibility in cultivation techniques. Both species are eurythermal and show a surprisingly greater tolerance for higher, rather than lower seawater temperatures, but show a significant reduction of photosynthetic rate in air. The increased primary productivity of *Gelidium* in warm waters suggests a strong possibility for enhancing growth under certain mariculture conditions and for raising this species in naturally warm water. Colloids from both species, freshly harvested and from beach drift, produce usable colloids despite seasonal fluctuations in their physical properties. However, k-carrageenan from *Rhodoglossum affine* differs from agar in some physical properties (e.g., gelling/melting temperatures).

The physiological and ecological approach described here is necessary to lay the biological foundation for mariculture of a red alga. Success in large-scale mariculture lies in integrating this approach with continual biochemical assessment of the alga, paralleled by development of culture techniques and a strain-selection program.

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Cooperating Organizations
Carnegie Institution of Washington (Stanford, California)
Marine Bioassay Laboratory (Watsonville, California)
Marine Colloids of FMC (Rockland, Maine)

Genetic Program for Improvement of Carrageenan Production in *Gigartina*

John A. West, Esther L. McCandless, and Kenneth G. Spencer

Genetic manipulation and selection are widely applied and successful techniques for improving production and quality of many agricultural crops. These same techniques are now being used to achieve similar goals in mariculture. The carrageenans have important industrial and food uses as emulsifiers and stabilizers. We hope to increase understanding of the genetic nature of carrageenan synthesis, and to improve yield and quality of carrageenans by genetic selection of the marine red algae that produce these polysaccharides.

Gigartina subgenus *Mastocarpus* is a foliose carrageenan-producing red alga. There are about six species widely distributed in the North Atlantic and North Pacific. One undescribed species also occurs in Chile and perhaps in other localities in the Southern Hemisphere.

The life histories of each species fit into two patterns: most populations are apomictic--successive generations of female gametophytes reproduce asexually by carpospores; other populations exhibit an obligate sexual life history--dioecious foliose gametophytes alternate with crustose tetrasporophyte (*Petrocelis middendorffii* stage). Approximately 60% of the *G. papillata* populations (Alaska to Mexico) are apomictic. The southern populations are strictly sexual, whereas northern populations are predominantly apomictic. In *G. agardhii* (British Columbia to California) approximately 70% of the populations tested were sexual, requiring crossing of male and female plants in culture to produce the crustose *Petrocelis*-like phase. In contrast to *G. papillata*, *G. agardhii* evidenced no geographic variation in life history. *G. stellata* populations from the American (Canada and U.S.) and European (Denmark to Portugal) North Atlantic exhibit a pattern similar to that of *G. papillata*; the crustose tetrasporophytes of sexual populations are identical to *Petrocelis cruenta*, and southern populations are totally sexual. In Japan (Hokkaido) *G. ochotensis* and *G. pacifica* show a very high frequency (86%) of apomixis. In a few populations (<5%) it appears that sexual and apomictic reproduction are intermixed, either occurring simultaneously on one plant or varying seasonally.

We have studied the genetic relationships of populations within each species. In *G. papillata* four different breeding groups are evident on the basis of laboratory hybridization experiments with culture isolates from the entire geographic range. In *G. agardhii* all strains are freely intercompatible. In *G. stellata*, isolates (Iceland, Britain, France, Portugal, Spain) are divided into four breeding groups. The results are not complete for Japan. Only one isolate is available from Chile.

Interspecific hybrids developed from the following combinations. *G.* sp (Chile) x *G. papillata* (California); *G.* sp. (Chile) x *G. stellata* (France); *G. stellata* (France, Portugal) x *G. ochotensis* (Japan); *G. papillata* (Alaska) x *G. pacifica* (Japan); *G. papillata* (California) x *G. pacifica* (Japan). The F_1 tetrasporophytes of the California x Chile and California x Japan hybrids sporulated. The former produces viable tetraspore germlings, and the latter forms only abortive tetrasporangia. Hybridization studies are continuing.

European and Japanese isolates release a yellow substance (Gelbstoff) into the culture medium. Eastern Pacific populations do not. These water-soluble compounds have a strong UV absorbance at 250 nm and are probably phenolics.

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Cooperating Organizations

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An Exploratory Study of the Vegetative Propagation of Benthic Marine Algae

UC Santa Barbara
R/A-37
1979-80

Aharon Gibor and Michael Neushul

Our major goal is to develop appropriate techniques for vegetative propagation and selection of commercially important macroalgae such as *Porphyra, Gelidium, Eucheuma*, and *Macrocystis*. A main obstacle to the cultivation of isolated tissues and cells from marine algae was the presence on them of contaminating organisms such as bacteria and fungi. It was not possible to study the effects of organic nutrients and growth-stimulating substances until bacteria-free (axenic) cultures of such tissues became available. Thus the first objective of our research project was to develop a procedure for obtaining axenic fronds from algal material collected from nature.

Determination of Viability

A prerequisite of all experimental treatments of algal tissues with germicidal agents is that the treatment does not kill the algal cells as well as their contaminating bacteria. It is essential, therefore, to have good criteria for determining the viability of algal cells. It is important to note that some of the germicidal agents tend to act as fixatives and result in a lifelike appearance of the fixed tissues. The criteria that we adapted include the following:

1. Use of vital dies.
   (a) Neutral-red uptake and accumulation by live cells
   (b) Evans-Blue exclusion from living cells.
2. Fluorescence microscopy.
   The characteristic fluorescence of live cells can be distinguished from that of damaged cells. We found the change in fluorescence to be most useful and reliable for immediate evaluation of chemical effects on algal tissues. Using changes in fluorescence to assess damage to the algal cells enabled us to rapidly screen a large number of germicidal agents.

Removal of Macroepiphytes

Algae collected in nature are invariably infested with many epiphytes. Commonly, these can be removed by vigorous manual brushing of the surfaces. This procedure is tedious and laborious. We experimented, therefore, with several mechanical alternatives. Vigorous mechanical shaking in seawater removes many epiphytes. Shaking in a suspension of abrasive materials such as fine sand in seawater increases the efficiency of epiphyte removal. Best results were obtained, however, with ultrasound treatment. We found that most algal tissues were not damaged by treatment in an ultrasound cleaning bath for several minutes. The treatment can be repeated several times, with a change of seawater between treatments. Older, strongly cemented epiphytes were cropped close to the holdfast, but the holdfast itself was not dislodged. This procedure does not eliminate all the epiphytes, but it is very efficient as a preliminary cleaning. Before adapting the ultrasound procedure for treating delicate algal cells it is advisable to establish the specific organism's limits of tolerance to this treatment. We were successful in cleaning the giant cells of *Acetabularia* by sonication for periods of less than one minute. Longer treatments killed these delicate cells.

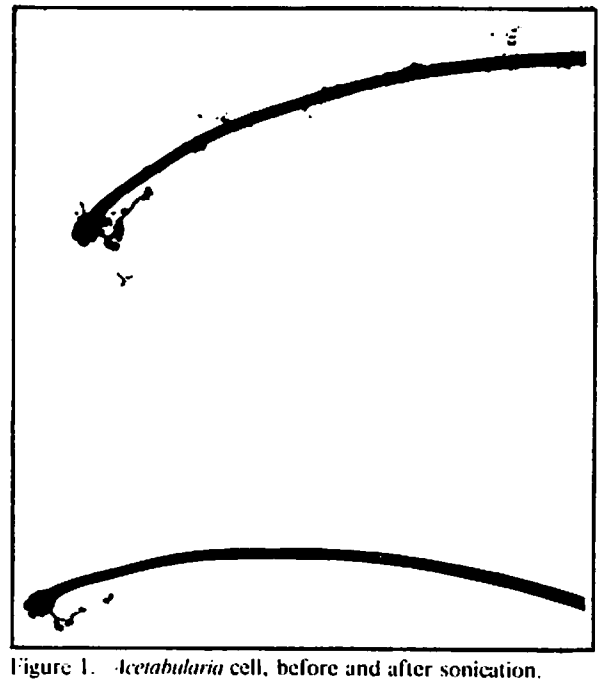

Figure 1. *Acetabularia* cell, before and after sonication.

Sterilizing Treatments

We tried the following germicidal agents: U.V. light, H_2O_2, Zephiran, Argyrol, Furazone-green, Hexachlorophene, Merthiolate, Naladixic acid, Betadine. We experimented with different concentrations and times of exposure. In general, the most efficient bactericidal agents were also fatal to the algal cells. The best treatment

we found was a short exposure, up to five minutes, to a solution of 1% Betadine. This is an iodinated polyvinyl pyrrollidone (I-PVP), which maintains a very low concentration of free iodine in its fresh solution. After the Betadine treatment the algal material was washed with sterile seawater and then submerged in a sterile solution of antibiotics in enriched seawater for one week. After the antibiotic treatment the algal fronds were washed and tested for sterility.

Sterility Tests

We checked the sterility of the treated algae by inoculating the treated tissues into diluted nutrient broth solution (0.1% nutrient broth [Difco] in seawater). Some samples were inoculated into the same broth, which was further enriched to 0.1% glucose and 0.1% yeast extract. In a third test we placed tissue samples on the nutrient broth solution, which was solidified with 0.6% agar. In some cases algal pieces that passed the nutrient broth test were transferred to the solidified agar plates for further testing.

It is important to stress that our claim to sterility of algal materials is defined by these sterility tests. We consider the tests adequate for the experimental purposes for which we are isolating these algal tissues. Remaining algal epiphytes are also likely to survive the sterilization procedures, thus in some cases we obtained bacteria-free but not unialgal material.

Conclusions

Through these procedures we have obtained sterile tissues from the following algae: *Porphyra lanceolata*, *Gelidium nudifrons*, *Gracilaria* sp., *Eucheuma uncinatum*, *Antithamnion* sp., *Prasinocladus* sp., and *Macrocystis pyrifera*. The efficiency of the sterilizing procedure depends on the state of the starting material. In some cases we obtained 90% of the tissue pieces in a sterile and viable state. We are using this general procedure routinely with modification, especially in the time of exposure to the Betadine solution appropriate to specific algal species.

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Food and Fiber from Seawater, Sand, and Solar Energy

UC Davis
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1979-80

Emanuel Epstein, Don L. Fredrickson, and Jack D. Norlyn

At many locations along the edge of the sea there is a constellation of resources not presently used much for the production of food and fiber: the seawater itself, the mineral nutrients in solution in it, expanses of sandy land, and solar energy. This project is meant to test the hypothesis that these resources can be used to produce green plants for food and fiber in a manner analogous to agriculture, but using these resources instead of good soils and fresh water. The present work is based on earlier research and development along this line, but differs from it in significant aspects.

Techniques and Procedures

Grains. The grains tested are barley, *Hordeum vulgare*, and wheat, *Triticum aestivum*. In earlier field tests of salt-tolerant selections of these grains, the plants were grown at Bodega Marine Laboratory on an area of stabilized dune sand, in the open. Rains were minimal during the first two years, and so, therefore, was dilution of the saline irrigations by rainwater. When normal rains returned after the drought years, dilution became a major problem. With financial assistance from the International Plant Research Institute, Inc., of San Carlos, California, we installed a plastic canopy over a site measuring 24 m x 30 m to protect the plots from rain (figure 1).

The 1980 season was the first one in which the canopy was used. Because we needed approval for its erection from the Coastal Commission (North Central Coast Regional Commission) and the Sonoma County Planning Commission, planting was much delayed (from an intended date of about December 1, 1979, to January 24, 1980).

Because of the lateness of the planting, and for other reasons discussed below, the seeds were allowed to germinate and seedlings to become established with fresh water. Then the experimental regimes were imposed sequentially, for eventual treatments of fresh water (control), 1/3, 2/3, and undiluted seawater.

Tomato. The experiments with tomatoes

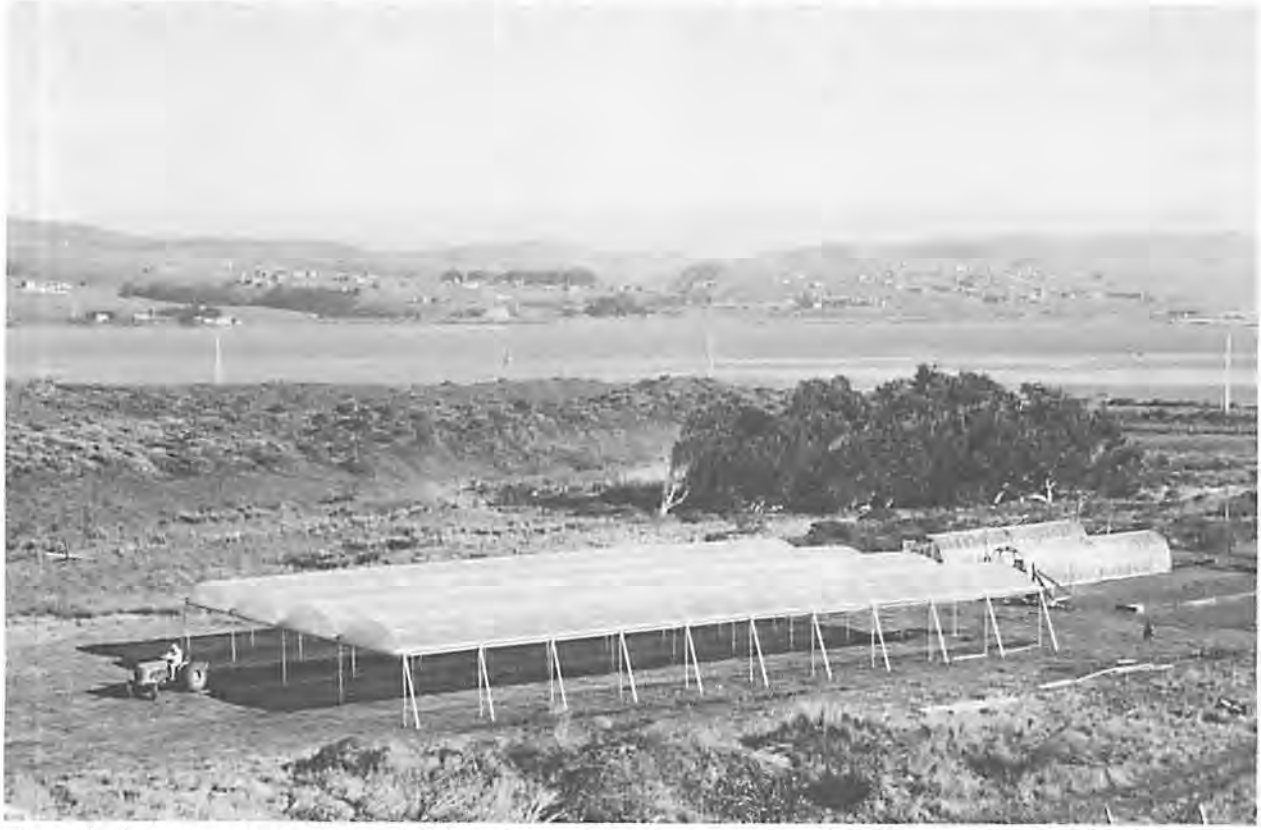

Figure 1. Canopy over an area of stabilized dune sand at the University of California Bodega Marine Laboratory. The canopy covers a 24 x 30 m experimental site for experiments on irrigation of barley and wheat with seawater and dilutions of it. It protects the saline treatments from dilution by rainwater. Partial assistance with the erection of the canopy by International Plant Research Institute, Inc. is acknowledged.

drew on earlier work in which progeny was obtained from an initial cross between the salt-sensitive, domestic *Lycopersicon esculentum* and the salt-tolerant, wild *L. cheesemanii*. The plants were grown in existing plastic shelters so that there was no problem of dilution by rainwater of the saline irrigations, nor delay in planting. There were two treatments: freshwater controls and 50% seawater.

Results

Barley. The mean yield for the undiluted seawater plots was 433 kg/ha, which is low, partly because of the lateness of the planting and partly because the salt stress was entirely unrelieved by any freshwater input once the seedlings were established. The corresponding values for the 2/3 and 1/3 seawater regimes were 1437 and 2390, evidence that brackish water irrigation, at least, can result in appreciable yields of barley.

Using salinized solution cultures in Davis, we find that there is in barley an especially salt-sensitive stage after the seeds have germinated, at about the three-four leaf stage. Salt tolerance is higher both before and after that stage. Both cultural and genetic approaches are being taken to overcome this difficulty. The most obvious cultural practice is to tide the plants over this sensitive stage by establishing the seedlings without salt stress, and this measure was adopted in this year's experiment, as described above.

Wheat. In general, the findings with wheat paralleled those with barley. In particular, wheat also has high sensitivity to seawater salinity at the three-four leaf stage. Selections from the world collection of wheat based on a screening of 5,000 of its approximately 33,000 entries can, however, survive at 50% seawater throughout their life cycle. Mean grain yields were low, for the same reasons mentioned above in connection with barley. Twenty-nine salt-tolerant lines of wheat have been identified, and 21 that are highly sensitive. Comparisons can thus be made of various physiological parameters between salt-tolerant and salt-sensitive selections.

Tomato. The tomato experiments were done in existing plastic shelters so that dilution by rainwater was no problem, nor was there delay in planting. All plant material was progeny from an original cross of the salt-sensitive, domestic *Lycopersicon esculentum* and the salt-tolerant but commercially useless wild *L. cheesmanii*.

This year's field trial at Bodega Marine Laboratory involved backcross 3 (BC_3). There were two treatments: fresh water (control) and 50% seawater. The experiment is still continuing, but certain conclusions can already be drawn. Fruit size and yield improve with each successive backcross; fruit size is reduced by the saline regime compared with that of the controls but is adequate, corresponding to that of large cherry tomatoes; uniformity of growth and yield improve progressively; salt tolerance increases consistently. Selected backcrosses not only survive even at 70% seawater but produce tomatoes, though with a low yield. These experiments are, to the best of our knowledge, the first ones to demonstrate the possibility of transferring salt tolerance from a wild to a domestic plant species.

Review

The literature on selection and breeding of salt-tolerant crops was extensively reviewed. We prepared a paper setting forth the present endeavors in our laboratory in the world-wide context of research and development devoted to salt-tolerant, economically useful plants.

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Cooperating Organizations

California Coastal Commission
International Plant Research Institute, Inc.
UC Bodega Marine Laboratory
Sonoma County Planning Commission

Fisheries

Development of Multispecies Management for Kelp Bed Resources with an Emphasis on Sea Urchins

UC San Diego
R/F-36
1978-80

Mia J. Tegner and Paul K. Dayton

Sea urchins are functionally the most important herbivore in the kelp communities of southern California and many temperate seas; their grazing activities can profoundly affect the distribution and abundance of numerous other organisms. While the incidence of destructive overgrazing has no doubt been reduced by the commercial fishery for red sea urchins (*Strongylocentrotus franciscanus*), these episodes are still occurring.

The objectives of this project have been twofold. First, we studied red urchin natural history and population dynamics on the heavily fished Channel Islands to develop the data base necessary for the management of this fishery. Secondly, we sought to determine the role of interactions with other species in controlling urchin populations, the foundation for a multispecies approach to the management of all kelp bed resources.

Through the cooperation of the Department of Fish and Game and use of their research vessels, we have up to four years of population data from the different Channel Islands. Analysis of annually-sampled size-frequency distributions indicates that there are two major patterns of population structure. Santa Barbara and San Clemente, hereafter referred to as the southern islands, have strongly bimodal size-frequency distributions with very high annual rates of recruitment and poor survival of the second-year class. This bimodality is similar year to year; it is not the result of successful year classes. We have also demonstrated that this bimodality cannot be explained by changes in the growth rate of mid-sized animals or by inadequate sampling of this size class. By contrast, the northern islands of San Miguel and Santa Rosa have considerably lower rates of recruitment but better survival of the second-year class. There is no evidence of consistent bimodality in these areas.

These two patterns, shown graphically in figure 1, appear to represent different production rates of fishable standing stocks as well as different mechanisms for the natural control of red urchin populations. The populations on the southern islands, which seem to be representative of red urchins on the warmer parts of the California coast down to the southern extent of their range in Mexico, are limited by predation on mid-sized animals. In the north, predation is much less severe, and red urchin populations are limited by recruitment. Data exchanges with colleagues to the north indicate that the pattern observed at San Miguel and Santa Rosa Islands holds from Point Conception to British Columbia. We are now attempting to determine average rates of production for these two patterns of red urchin population structure.

Competition and predation are biological interactions with obvious implications for the control of population size. For sea urchins in southern California, the apparent competitors are abalones (several members of the genus *Haliotis*), and the important predators are spiny lobsters (*Panulirus interruptus*) and the California sheephead (*Semicossyphus pulcher*). Abalones, lobsters, and sheephead are all harvested by both sport and commercial fishermen.

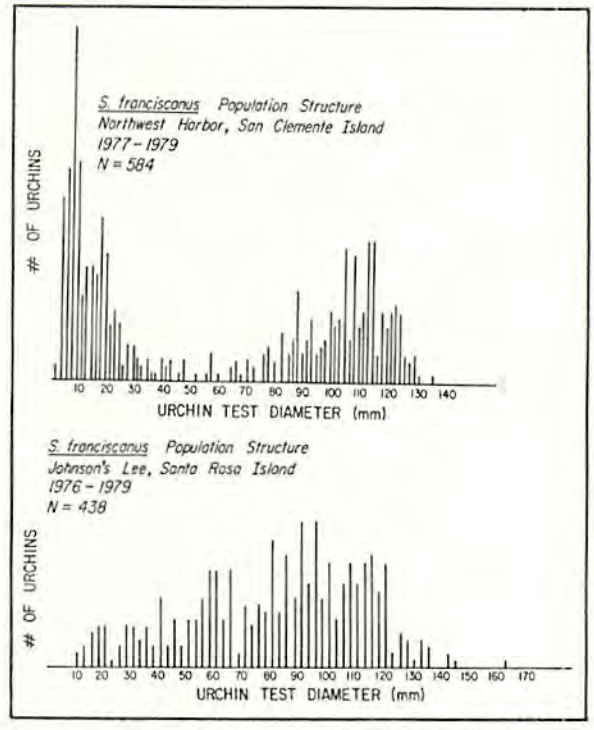

Figure 1. These size-frequency distributions illustrate the two different types of red urchin populations found in the southern California bight. At San Clemente, which is typical of the warmer areas, recruitment occurs at high rates, and predation on mid-sized animals appears to control population size. At Santa Rosa, a colder habitat, predation is much less important, and low recruitment rates probably limit population size.

As with most current fisheries management, catch regulations for these species were based solely on their individual biologies. The impact of these fisheries on the community as a whole was not considered.

Sharing similar food and habitats, sea urchins and abalones seemed likely to be competitors. Abalones were subjected to intensive fishing pressure, and landings had declined considerably by the time of the so-called urchin "population explosion" about twenty years ago. We investigated the hypothesis that red (*H. rufescens*) abalones are superior competitors for food--i.e. that the apparent increase in red urchin populations after the heavy fishing of abalones was a result of competitive release--by comparing the growth of both herbivores in mixed and single species groupings under different conditions of food supply in aquaria. Depending on the food supply and size of the animals, competition with abalones did, in some instances, depress urchin growth rates. We conclude, however, that competition with abalones for food is not a major factor affecting urchin population size. Our observations that urchins have different foraging strategies and occupy slightly but significantly different habitats further support the conclusion that these animals are not direct competitors.

In contrast, the case for lobster and sheephead predation affecting sea urchin distribution and abundance is strong. Where these predators are abundant, many urchins are found in refuges. Where these predators are rare or absent, more urchins are out in the open. Field and laboratory experiments indicate that these predators are responsible for the bimodal size distribution. The first peak can be accounted for by the protection of young urchins under the spine canopy. Mid-sized animals too large to get protection from adults are the most vulnerable to predation. Large red urchins with their formidably long spines attain partial refuge in size. (The second peak of the bimodal distribution represents the accumulation of several year classes as urchin growth rates slow.) Lobsters and sheephead are both common on the southern islands; both are rare or not present on the northern islands.

Thus, destructive urchin overgrazing is less likely to occur where these predators are abundant. This prediction was supported by Dayton's (in preparation) eight-year study of giant kelp (*Macrocystis pyrifera*) mortality at Point Loma and illustrates the potential benefits of a multispecies approach to management of kelp bed resources.

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Cooperating Organizations

California Department of Fish and Game

Endocrinology of Normal and Abnormal Salmon Smoltification and Adaptation to Seawater

UC Berkeley
R/F-45
1978-80

Howard A. Bern, Richard S. Nishioka, E. Gordon Grau, Khiet V. Lai, Nathan Collie, Christopher A. Loretz, N. Harold Richman, and Thomas Gross

In California, coho salmon (*Oncorhynchus kisutch*) are reared in hatcheries to enhance propagation that has been reduced by human intervention; however, certain factors counter these efforts after the young salmon leave the hatchery. Our interest in the endocrinology of salmon smoltification was stimulated by the fact that losses of up to 50% occurred when coho failed to grow after transfer to seawater net pens. The "stunting" observed within the protective confines of a net pen led to the recognition of the possibly enormous losses occurring in nature when juvenile salmon at an incomplete stage of development (smoltification) are released directly or transported from hatcheries for subsequent release. Fish that become stunted in the open sea are presumably lost to predation. We are studying several aspects of endocrine function and possible dysfunction during development and seawater adaptation in order to clarify and devise means to alleviate this problem.

We have analyzed various physiological and morphological changes accompanying coho salmon smoltification, using Trinity River stock coho raised in the Mad River Hatchery near Eureka. Additional plasma samples were collected and sent to us from the Iron Gate Hatchery near Yreka. Coho samples were obtained from late January to June, generally every two weeks. We have collected data relevant to thyroid gland physiology and morphology, urophysial activity, epidermal structure, responses to seawater challenge (trainee N.H. Richman), and intestinal fluid absorption (trainee N. Collie).

Studies of thyroid activity during smoltification have proved most promising. Determining the optimal time for releasing hatchery-reared anadromous salmonids has long been an important concern for those in hatchery management. Like amphibians, salmonids show a developmental surge of thyroid activity coincident with the metamorphosis (smoltification) of freshwater parr to seawater-adaptable smolt. Folmar and Dickhoff (personal communication) have shown that the ability to grow and survive in seawater is directly related to the proportion of the thyroxin (T_4 measured by radioimmunoassay or RIA) "surge" completed prior to seawater entry. This T_4 surge appears to be an excellent predictive indicator for seawater readiness. However, the T_4 surge has been observed to vary from year to year by as much as two weeks. This has required investigators to monitor individual stocks closely--a time-consuming and expensive process.

In collaboration with the California Department of Fish and Game and colleagues at the University of Washington, we have recently determined that the T_4 surge is coincident with the new moon phase of the lunar cycle following the vernal equinox in California, occurring one month later in Washington State. We found this correlation among 27 different stocks to be highly significant by several statistical criteria. This year (1980) two California hatchery stocks of coho salmon (Mad River/Trinity stock and Iron Gate) reached their peaks in coincidence with the new moon in mid March. The ability to predict migratory readiness by lunar calendar should minimize the need for sampling and complicated technology and thus may have substantial implications for efficient culture.

To study the effects of seawater entry on thyroid gland function, we transferred fish into seawater on a regular schedule. The transfer of coho salmon to seawater caused a substantial 24-hour drop in plasma thyroxin (T_4), which was most pronounced during the T_4 surge in spring. In order to determine possible reasons for this drop, we conducted T_4 turnover studies. Metabolic clearance and degradation of radiolabeled T_4 were also significantly reduced after seawater transfer. Taken together, these findings indicate that thyroid function is strongly inhibited, at least temporarily, following seawater entry. Inasmuch as thyroid hormones have been repeatedly shown to be essential for normal growth and development in vertebrates generally and in salmon specifically, this reduction in T_4 secretion, if chronic, may be a major cause of stunting by coho salmon in seawater.

The effect of stimulating the developing thyroid gland by ovine thyrotropin (oTSH) was studied by light- and electron-microscope examination of the gland, in addition to RIA of blood samples for thyroxin. Histological and ultrastructural features of thyroid gland structure in coho salmon were examined following treatment

in early March 1980 with doses of oTSH ranging from 0.05 to 0.8 IU. Plasma T_4 ranged from 0.64 ng/ml in controls to 24.5 ng/ml in maximally stimulated fish. In light-microscope observation of 1-μm thick sections stained with methylene blue and azure II, oTSH treatment increased the number of follicles that were reduced in size. Within these follicles cell volume increased. In addition, ultrastructural observation revealed more extensive rough endoplasmic reticulum and Golgi apparatus with an increase in the numbers of dense vesicles and mitochondria in the oTSH-treated fish. These changes produced by oTSH in coho salmon are similar to those described for other vertebrates. Additional morphological studies of the changes in thyroid structure correlated with development are in progress.

"White cells" from a predetermined area of the subopercular epithelium were counted to determine whether the data from Mad River stock collected in 1979, which closely paralleled changes in plasma T_4 levels, could be duplicated. There was no pattern discernible in Trinity stock reared at Mad River in 1980. In addition, scanning electron-microscope examination has revealed no obvious changes in the subopercular epithelial surface.

Development of osmoregulatory mechanisms necessary for seawater survival is considered to be an essential aspect of smoltification. Results from the Mad River stock in 1979 suggested that the development of these mechanisms is reflected by lower increases in plasma Na^+ Mg^{++} and Cl^- after 24-hr challenge of coho by transfer to seawater. In 1980, seawater challenge of Trinity stock coho exhibited wide variation in plasma Na^+ increases, with only minimal evidence of improved response as smoltification progressed. We are currently analyzing other plasma ions. Although the differences between 1979 and 1980 results raise questions about the reliability of seawater challenge tests for degree of smoltification, the plasma thyroxin levels were low and possibly bimodal in the 1980 stock compared with the 1979 Mad River stock, which may be related to the ambiguity of this year's results.

A reliable technique for the bioassay of salmon prolactin and possibly growth hormone is now available in our laboratory using hypophysectomized *Fundulus heteroclitus*. We are using this bioassay in our efforts to purify coho prolactin and growth hormone; purified hormones in turn will lead to the development of RIA methods for their measurement in circulating blood.

In general, our endocrinological analysis of normal and abnormal salmon development is providing information not only of fundamental but also of practical significance. As an example of the latter, our new moon/degree of smoltification hypothesis described above, and now in press in *Science*, has aroused considerable interest at the Anadromous Fisheries Branch of the California Department of Fish and Game, and elsewhere, including Washington, Canada, and Japan. As a consequence, several regional offices within the California Department of Fish and Game are currently planning their hatchery salmon releases in consultation with us.

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Cooperating Organizations

California Department of Fish and Game: Region 1 Iron Gate Hatchery, Mad River Hatchery
Japanese National Institute for Basic Biology
National Marine Fisheries Laboratory, Cook, Washington
National Marine Fisheries Service, Manchester, Washington
National Marine Fisheries Service, Tiburon Laboratory
National Science Foundation
University Cooperative Extension, Sonoma County, California
University of Hakodate, Japan
University of Tokyo
University of Washington, Seattle

Artificial Imprinting of Chinook and Coho Salmon in a Multispecies Hatchery

Humboldt State
R/F-46
1978-80

Thomas J. Hassler and Robert Will

The principal method that salmonids use to identify their home area appears to be olfaction. Hasler and Wisby (1951) theorized that the specificity of homing was due to the detection of distinct odors in the home stream. Their later studies, along with others, have shown that olfaction is the major mechanism that directs the freshwater migratory behavior of salmonids (Wisby and Hasler, 1954; Hasler, 1956, 1960, 1960, 1966; Harden-Jones, 1968; Kleerekoper, 1969; Brett and Groot, 1963; Groves et al. 1968).

The homing ability of salmon does not appear to be inherited. Jensen and Duncan (1971), Carlin (1968), and Vreeland et al. (1975) showed that juvenile salmon removed from their home stream prior to migration and transported and released into another stream or hatchery would return to the release site. Donaldson and Allen (1957) removed salmon fingerlings from their natal streams and let the fish develop in different waters. The adults homed to the water where the fingerlings were raised, not to the parent stream. Therefore, homing is connected, in part, to a rapid and irreversible learning period prior to seaward migration. This type of behavior has been termed *imprinting* (Hasler and Wisby, 1951; Brett and Groot, 1963; Mayr, 1974; Hasler, 1966; Harden-Jones, 1968).

It has been theorized that during the imprinting period, salmon learn the odors of their natal stream and subsequently use this information to locate their home stream during the spawning migration (Hasler and Wisby, 1951; Hasler, 1966). Hasler and Wisby (1951) also suggested that it might be possible to artificially imprint salmon by exposing them to a synthetic chemical and then, later, to scent a specific area with the chemical to attract the fish.

Morpholine, an organic compound, has been selected for chemical imprinting of salmonids because (1) it is not known to occur in natural waters; (2) it is highly soluble in water; (3) it is probably stable in the natural environment; and (4) this compound can be detected by coho salmon at low concentrations (about $1x10^{-5}$ mg/l) (Scholz et al. 1975). Recently, Cooper (1974), and Cooper and Hasler (1973, 1974, 1975), reported that coho salmon and steelhead trout could be imprinted to morpholine.

Currently, there is no information on the enhancement of returns to precise fish hatcheries. And past studies have not investigated the effects of imprinting on an ocean run anadromous species of salmon, which would have a larger migrational range and an ocean residency before returning to fresh water.

Mad River Hatchery, one of six salmon and steelhead hatcheries operated by the California Department of Fish and Game, is the only hatchery designated to maintain and enhance salmonid runs in California. The hatchery, located 19 km from the ocean on the Mad River, presently produces chinook and coho salmon and steelhead trout. The hatchery was designed to raise 5,000,000 chinook salmon to an age of 90 days; 200,000 yearling silver salmon; and 700,000 yearling steelhead. To produce this number of chinook fingerlings, an egg take of 7,000,000 from 1500 mature females is needed. An egg take of 280,000 from 140 mature females is necessary for coho salmon. The mean annual return of female chinook and coho since 1972 has been only 146 and 80 fish, respectively--well below numbers desired for full production. The low return of mature salmon may be due, in part, to poor homing of fish to the hatchery fish ladder.

Mad River Hatchery raceways are supplied by recirculated well water with partial make-up, while the fish ladder is supplied by single-pass river water composed of about 20% hatchery water and 80% river water. Thus, the hatchery water is not fully utilized as a homing attractant. Therefore, returning chinook and coho salmon may fail to locate or "recognize" the fish ladder and may continue migrating upstream.

The specific objective of this study is to investigate the possibility of significantly increasing numbers of chinook and coho salmon returns to Mad River Hatchery by imprinting the juveniles with morpholine, and later attracting them when they have matured and returned.

Materials and Methods

The Mad River Hatchery 1977 and 1979 brood year chinook salmon and the 1977 and 1978 brood year coho salmon were each divided into two groups--treated and control. The treated group was exposed to morpholine,

$5x10^{-5}$ mg/l, for three weeks prior to release. Both groups were handled the same and clipped or nose tagged before release to the Mad River. The Na^+ and K^+ ATPase activity was monitored, and the fish were released when the enzyme activity was at its peak.

Morpholine was metered into the raceway from a stock solution by a preset metering pump. The concentration in the raceway was approximately $5x10^{-5}$ mg/l. Morpholine was added to the fish ladder water by the same system when the salmon returned to the hatchery. The ladder water contained approximately the same concentration of morpholine as the raceway.

Results

We originally planned to imprint the 1978 brood year chinook salmon as 90-day fish in the spring of 1979. However, California Fish and Game decided to release the Mad River Hatchery chinook as yearlings instead of 90-day fish. This change in policy allowed us to start the project using the 1977 brood year fish as yearlings in the fall of 1978. We marked and imprinted 41,500 fish and marked 42,100 control fish. We had planned to replicate the experiment using the 1978 brood year chinook, but because of low river flow, only 13 fish were spawned at the hatchery. The resulting production, 28,000 fish, were contaminated with "Sacramento River chinook disease" and later stocked in the Sacramento River. In order to replicate the experiment we marked and imprinted the 1977 brood year coho salmon, 38,418 control and 50,800 treated fish, fall 1979.

In 1980 we were able to mark and imprint replicate lots of each species. We marked and imprinted the 1978 brood year coho salmon--8,367 control and 11,170 treated fish--and nose tagged the 1979 brood year chinook--19,200 control and 19,800 treated fish.

Adult salmon returns to Mad River Hatchery were monitored during the 1979 spawning season. The synthetic odor morpholine, the chemical used to imprint juvenile salmon prior to their release from the hatchery, was added to the hatchery raceway as an attractant during the 1979 spawning run. Seventeen "jack" chinook salmon were captured--nine imprinted and eight control fish. Coho "jack" returns were higher, with 38 fish counted. Of the 38 coho returns, 25 were imprinted fish and 13 were control fish. At least for "jacks", it appeared that morpholine had a significant effect on coho returns but a nonsignificant effect on chinook returns. The morpholine station is in place at the hatchery fish ladder, and the 1980 adult returns are being monitored.

Salmon from the various imprinted brood years will continue to return to the hatchery through the 1983 spawning season, so it will be a number of years before all the data are available for analysis.

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Cooperating Organizations

California Conservation Corps
California Cooperative Fishery Research Unit, USFWS

Experimental Abalone Enhancement Program

UC San Diego/UC Santa Barbara
R/F-47A&B
1978-80

Mia J. Tegner, Joseph H. Connell, Robert W. Day, Russell J. Schmitt, Stephen Schroeter, and John B. Richards

The first large-scale seeding experiment with red abalone (*Haliotis rufescens*) was established at Lunada Bay, inside the closed area at Palos Verdes, in November 1978. Ten thousand animals, in two size classes, were planted into an area with habitat similar to that in which we had our best results in the small-scale experiments at Point Loma.

Mortality during the first month was assessed by collecting shells (or shell parts) and noting the condition and location of each. Octopuses appear to be the most important predator, accounting for about 43% of the observed mortality in the first month. Other important predators are cabezon, crabs, lobsters, and starfish. Based on the collection of shells, mortality associated with planting and the initial adjustment to the bottom was less than 2%. While this figure is undoubtedly low, since some shells become hidden or destroyed completely, the rate was considerably lower than that observed in some of our experiments at Point Loma, evaluated in the same manner.

One year later, we conducted a detailed evaluation of this experiment. As expected from Japanese seeding experiments, we found few live animals, as the seed had grown into the very cryptic, intermediate-size class. Those we found showed growth of up to 55 mm in one year, an excellent rate, which indicates that these animals adapted very well. We recovered a range of shells of dead animals, from those exhibiting no growth (which presumably died soon after planting) to ones that still had some flesh inside and had grown considerably. Forty-four percent of the recovered shells were drilled, presumably by octopus. Our data indicate that these cephalopods do not drill all their abalone prey, especially smaller ones. This suggests that the real mortality from octopus predation is considerably higher. We will continue to evaluate this experiment annually by collecting shells and censusing live animals. The most important data will be that collected when the abalones grow into emergent size classes, probably one or two years hence.

Two other large-scale red abalone seeding experiments have been established. The first is located at Tyler Bight on San Miguel Island, a Channel Island site chosen as a clean-water control to our mainland studies. The object of this experiment is to determine size-specific survivorship, important data in considering optimal seed size. Approximately 10,000 abalones were planted in each of four size classes: 11, 20, 28, and 34 mm. A second experiment was started at Palos Verdes, in a habitat selected for its contrasts to the first site. Point Vicente is exposed to considerably more water motion than Lunada Bay, so it has less sediment and a significantly different algal community. The optimal time for full-scale evaluation of these two experiments will be determined from the results of the annual surveys at Lunada Bay.

Hatchery problems with spawning green (*H. fulgens*) and pink *(H. corrugata)* abalones have delayed work with these species. We received our first green seed in 1980, and preliminary data are very encouraging. They appear to be growing as well as reds. But, in sharp contrast to the reds, greens seem to remain in the same area. This will make evaluation of seeding experiments considerably easier.

We made two cruises to Santa Barbara Island to study the natural history of green abalones in preparation for green seeding experiments at Palos Verdes. This species lives in a very different habitat from that of the red abalones. Rock outcrops of 1 to 1.5 m relief with narrow overhanging or undercut bases, adjacent channels of sand and turnable rock, beds of *Phyllospadix*, turf algae including articulated coralines and foliose reds, and clean rock surfaces are important parameters of green habitat.

In addition to seeding hatchery-reared juveniles, we are testing three other experimental approaches to abalone enhancement: transplanting adults as brood stock, closing an area until it rebuilds naturally, and modifying habitat to improve the settlement of native abalones and survival of native and seeded stocks. We are testing the first and second of these approaches at Palos Verdes with an extensive censusing program. Preliminary results indicate that the closure is affecting adult populations, an important consideration for animals with such a short larval life. One explanation for the present species abundances is the relative colonizing abilities of the different species. The most abundant species today is the one with the best

potential colonizing ability. Conversely, the least abundant has the shortest larval life and spawns during summer months of lower average currents--characteristics suggesting that it is the poorest colonizer. If we can verify this experimentally, a large-scale transplant of adults of the poorest colonizer will be conducted to provide an endemic source of larvae.

Our previous work suggested the importance of adequate nursery habitat to abalone population size. Southern California Edison and the Department of Fish and Game used our data to design eight experimental artificial reefs near San Onofre. Four of these were constructed with nursery habitat and four without. Two of each will be seeded with hatchery-reared juveniles, and two of each will be followed for the settlement and survival of native abalones. If our hypothesis is supported, habitat modification may be an effective approach for enhancing populations in certain areas where poor habitat apparently limits native abalone productivity. We may also find, as the Japanese apparently have, that some degree of habitat modification would be a cost-effective way to increase the return from seeding operations.

Related Research at UC Santa Barbara

The general aim of the Santa Barbara Enhancement Group was to examine the possibility of augmenting depleted stocks of red abalone (*Haliotis rufescens*) in nature by "planting" juveniles that had been raised for one to two years in shoreside hatcheries. Our specific objectives were to (1) determine whether seeding juvenile red abalone can increase juvenile stocks on depleted reefs, (2) establish characteristics of abalone behavior that may affect seeding success, (3) describe features of the physical habitat where juvenile red abalone occur, and (4) elucidate predator-abalone interactions that have an important influence on juvenile abalone survival. All of these goals were met. The first year of the project we established field study sites and launched laboratory experiments. In the second year we made two test plants and conducted all other field experiments.

Experimental Plants of Hatchery-Raised Abalone

Two experimental plants of juvenile abalone were made at Naples reef, Santa Barbara County. We selected a habitat typical of nearshore reefs in the Santa Barbara area. It consisted of an extensive series of rock ridges with boulders at the base protruding from wide sand channels. Two sites, each 6000 m^2 in area (75 x 80 m), were established at depths of 12-15 m. Intensive sampling indicated that juvenile red abalone naturally occur only under boulders, principally at the base of the ridges. The availability of this suitable habitat, estimated by twelve 60 x 1 m belt transects per site, was approximately 25% (1500 m^2) of the total area in both the experimental and control sites. Eight permanent transects, each 10 x 1 m, were placed in the boulder areas of both plots. These permanent lines were sampled for abalone density immediately before and four months after seeding abalone. Seeded animals were hand-placed under boulders in batches of one to five.

The first test plant was begun in mid-November, 1979, and evaluated in late March, 1980. A total of 9945 abalone from a single hatchery were seeded. The planted animals were less robust than native juveniles; they had thinner, more eroded shells with fused respiratory pores. The seeded animals ranged in size from 20-40 mm, with an average length of 31 mm. Statistical analysis of data from the permanent transect showed that seeding did not increase juvenile abundance after four months. Only two hatchery abalone were found alive. We have some evidence that the planted abalone suffered high mortality. Within two days of the seeding we witnessed starfish and gastropod predators consuming planted animals. A total of 431 shells of seeded juveniles, representing 4% known mortality, were collected during the first 21 days following the plant. Of these shells, 8% had been drilled by octopus, and 11% killed by crabs or lobster. The plant could not be monitored between mid-December, 1979, and early March, 1980, because of winter storms; we do not know what effect these storms had on the planted abalone.

The second test plant was started in mid-May, 1980, and monitored twice weekly until early September, 1980. In total 8916 abalone from three hatcheries were seeded; the range in size was from 10-40 mm, and the average length was 18 mm. Analysis of juvenile abundance in the permanent transects revealed that the experimental area contained significantly more juveniles four months after seeding; juvenile density changed from 0.33 per 10 m^2 initially to 3.88 per 10 m^2 four months after seeding. This is statistically significant. The fact that the control site did not show any change in juvenile abundance during the same time period

indicates that planting, not natural recruitment, was responsible for the enhanced juvenile population in the experimental area.

As a result of the second plant, the absolute abundance of juvenile abalones in the small planted area was increased by 600-1000 animals. We have data that suggest the planted abalone incurred relatively low mortality and that many of the animals may have simply emigrated from the study plot. In order to estimate mortality, we systematically searched for shells of dead seeded abalone each week. Only 529 shells were collected, representing just 6% known mortality in 120 days; this is a monthly rate of 1.5% (table 1). Of the 529 shells, 1% had been drilled by octopus, 1% drilled by carnivorous snails, 2% killed by fish, and 11% taken by crabs or lobster.

The known mortality figure does not account for shells that were overlooked or otherwise lost. It also does not include animals that emigrated before dying. We were able to improve the accuracy of the mortality estimate by seeding 1194 marked abalone shells (size range: 13-42 mm) in our control plot to obtain an approximation of natural shell loss and of our searching efficiency for different size classes of shells. By the end of four months, 71% of the marked shells had been recovered (table 2). We used the proportion of each size class found to adjust the known mortality figure. This gave an estimated mortality rate of 8% in 120 days, or 2% per month (table 1). A more accurate approximation would also consider the mortality of emigrants. One way this can be incorporated is to calculate mortality based on the average number of abalone in the study plot during the four-month period. This additional refinement yields an estimated motality rate of 16% in 120 days, or 4% per month (table 1).

We also explored the possibility that most seeded abalone dispersed out of the relatively

Table 1
Mortality Estimates for Juvenile Red Abalone Seeded at Naples Reef in May 1980

	Method	Assumptions	Mortality per Month	Estimated Seed* Longevity
Known mortality	1. Collection of shells from plant	1. No shells are overlooked or lost 2. No live animals emigrate	1.5%	5.6 years
Adjusted mortality First estimate	1. Collection of shells from plant 2. Estimate of shell loss 3. Estimate of shell-size searching efficiency	1. No live animals emigrate	2.0%	4.2 years
Adjusted mortality Second estimate	1. Collection of shells from plant 2. Estimate of shell loss 3. Estimate of shell-size searching efficiency 4. Estimate of emigration		4.0%	2.1 years

*Assumes no decrease or increase in mortality with increasing abalone age.

Table 2

	Marked Shells			Test Plant Abalone			
Size Class	No. Seeded	No. Found	Fraction Found	No. Seeded	No. Dead* Shells	Adjusted No. Shells	Proportional Mortality per Size Class
< 13 mm	0	0	-	2169	20	67	0.03
13-15 mm	37	11	0.30	1488	25	83	0.06
16-18 mm	13	8	0.62	1290	39	63	0.05
19-21 mm	45	27	0.60	1166	55	92	0.08
22-24 mm	26	26	1.00	1097	97	97	0.09
25-27 mm	223	210	0.94	775	111	118	0.15
28-30 mm	274	195	0.71	558	85	120	0.22
31-33 mm	136	82	0.60	211	32	53	0.25
34-36 mm	238	172	0.72	130	18	25	0.19
37-39 mm	125	72	0.58	26	9	16	0.62
40-42 mm	77	45	0.58	6	1	2	0.33
Total	1194	849		8916	492	736	

Data summary of abalone sizes planted and shells recovered in the May, 1980, plant at Naples reef. Also included are data on the sizes of marked shells "seeded" and recovered as an estimate of natural shell-loss and finding efficiency.

*Does not include 37 broken shells

small study plot. Short-term experiments indicated that juveniles 20 mm in length can travel 90 meters of straight-line distance in 30 days. Widespread searches of areas adjoining the experimental site revealed hatchery abalone as far away as 200 meters.

Behavior of Hatchery Abalone

Short-term field experiments clarified the tendency of hatchery abalone to leave an area where they are planted. One experiment compared the emigration of abalone from three different hatcheries with that of similar-sized native juveniles. Equal numbers (100 each) of the four abalone types were seeded on an isolated reef 80 m^2 in area). All abalone that remained were collected 30 days later. Only 6% of the hatchery abalone were found, compared with 27% of the natives: this is statistically significant. The difference is probably not due to differential mortality, since the amounts of dead shells of native (2%) and of hatchery animals (6%) collected were not significantly different.

Another experiment examined the effect of seeding density on emigration rate. Five hundred hatchery abalone were seeded on four isolated reefs--two of moderate area (50 m^2) and two with small surface area (5 m^2). Hence, emigration rates between moderate ($10/m^2$) and extremely high ($100/m^2$) seeding densities could be compared. Significantly more animals left both of the high-density reefs in 30 days, compared with the two moderate density areas. However, all four reefs had abalone densities of between 4-8 per 10 m^2 at the end of 30 days, a density figure that matches well with the results of our second test plant.

We discovered that hatchery abalone 20-30 mm in length tend to return to the same crevice after foraging. Using this fact, we devised a series of laboratory experiments to determine what factors alter this behavior. The results, summarized in table 3, reveal several important points. Larger (40 mm) and much smaller (12 mm) juveniles apparently do not show this "homing" behavior. Individuals tended to select the crevice nearest to upstream food, but displayed no crevice preference when the food was downstream. When two abalone were present, both individuals shared the same crevice and displayed great fidelity to it. Both dis-

Table 3
Factors Affecting Shelter Fidelity of Juvenile Red Abalone

Treatment	Results
1. Size of abalone	20-30 mm animals display high shelter fidelity 40 mm & 12 mm animals show low fidelity
2. Position of food with respect to current	Food upstream: animals display high shelter fidelity animals prefer shelter nearest food Food downstream: animals display high shelter fidelity animals show no shelter preference
3. Shelter disturbed	Decreases shelter fidelity
4. Two abalones in same tank	Increases shelter fidelity Animals share same shelter
5. Scent of starfish predator	Lowers shelter fidelity

turbance of the crevice and the presence of starfish scent decreased abalone homing behavior.

Our laboratory experiments revealed that hatchery abalone are behaviorally different from native individuals of the same size. Two characteristics may increase the susceptibility of hatchery animals to predation. Compared with natives, hatchery juveniles foraged out of their shelters for significantly longer periods at night. Second, when the scent of a predatory starfish was perfused through a tank, native abalone displayed a significantly greater escape response; hatchery animals tended to forage normally.

Characteristics of the Physical Environment

Correlations between juvenile abalone abundance and features of the microhabitat revealed several important points. Juveniles occur more often than expected, based on the relative abundance of rock sizes, under relatively large boulders (0.5 m^2 in area) and less often under small boulders (0.1 m^2 in area). However, abalone are equally abundant per unit surface area on large and small boulders. The texture of the boulder undersurface appears important: virtually no juveniles occur under rocks with deeply pitted bottoms. These boulders are common at Naples Reef, and abalone may be avoiding them. The substrate upon which boulders rest (rock, sand, cobble) does not influence abalone occurrence.

Predator-Abalone Interactions

In the laboratory, cancer crabs and a starfish (*Pycnopodia*) were the most voracious invertebrate predators of abalone. Octopus, as well as the starfish *Pisaster* and *Astrometis*, consumed abalone at a very low rate in the laboratory. The starfish *Orthasterias* and the whelk *Kelletia* did

not eat live abalone. All but the very smallest predators could consume an abalone as large as 50 mm. Replicated laboratory experiments indicate, however, that abalone in the 20-25 mm size range are much more susceptible to predation than are 35-45 mm individuals.

Conclusions

The result of the second test plant is the most promising outcome of an abalone seeding experiment to date. It is especially significant since the habitat planted now supports a sparse adult population; this suggests that enhancement of depleted areas may be quite feasible. Additional field and laboratory experiments suggested important aspects of juvenile abalone behavior that may influence the success of a plant.

Publications

Morse, D.E., M. Tegner, H. Duncan, N. Hooker, G. Trevelyan, and A. Cameron. Induction of settling and metamorphosis on planktonic molluscan *(Haliotis)* larvae. III: Signaling of metabolites of intact algae is dependent on contact. In *Chemical Signals*, D. Muller-Schwarze and R.M. Silverstein, eds. Plenum Publishing Corporation, 1980. pp. 67-86.

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Cooperating Organizations

California Abalone Association
California Department of Fish and Game, Santa Barbara County
California Department of Fish and Game, State
Southern California Edison
Tatman Foundation
Ventura County

Sensory and Behavioral Effects of Pollutants on the Crab and Lobster Fishery

UC Santa Barbara
R/F-48
1978-80

James F. Case

The aim of this study has been to examine two closely related problems important to the local crab and lobster fishery: (1) the efficiency and possible improvement of baits currently in use, and (2) the possibility that petroleum fractions naturally or accidentally occurring in the environment may influence the sensory processes used by crabs and lobsters in finding traps.

Studies were conducted in laboratory and field. In the laboratory, we made electron microscopical and electrophysiological studies of crustaceans to assess the effects of petroleum, natural stimulants, fractions of natural stimulants, and synthetic stimulants on chemoreceptors responsible for taste and olfaction. We used information from these studies to test the stimuli required to initiate near-field and far-field food search by crabs and lobsters. Next, we conducted a large series of field tests with a trapping array to translate laboratory findings into the practical realm. Finally, individuals from the Santa Barbara shellfishing community are cooperating in commercial testing of ideas emergent from these studies.

Petroleum Effects

Inspection of various crustaceans from the

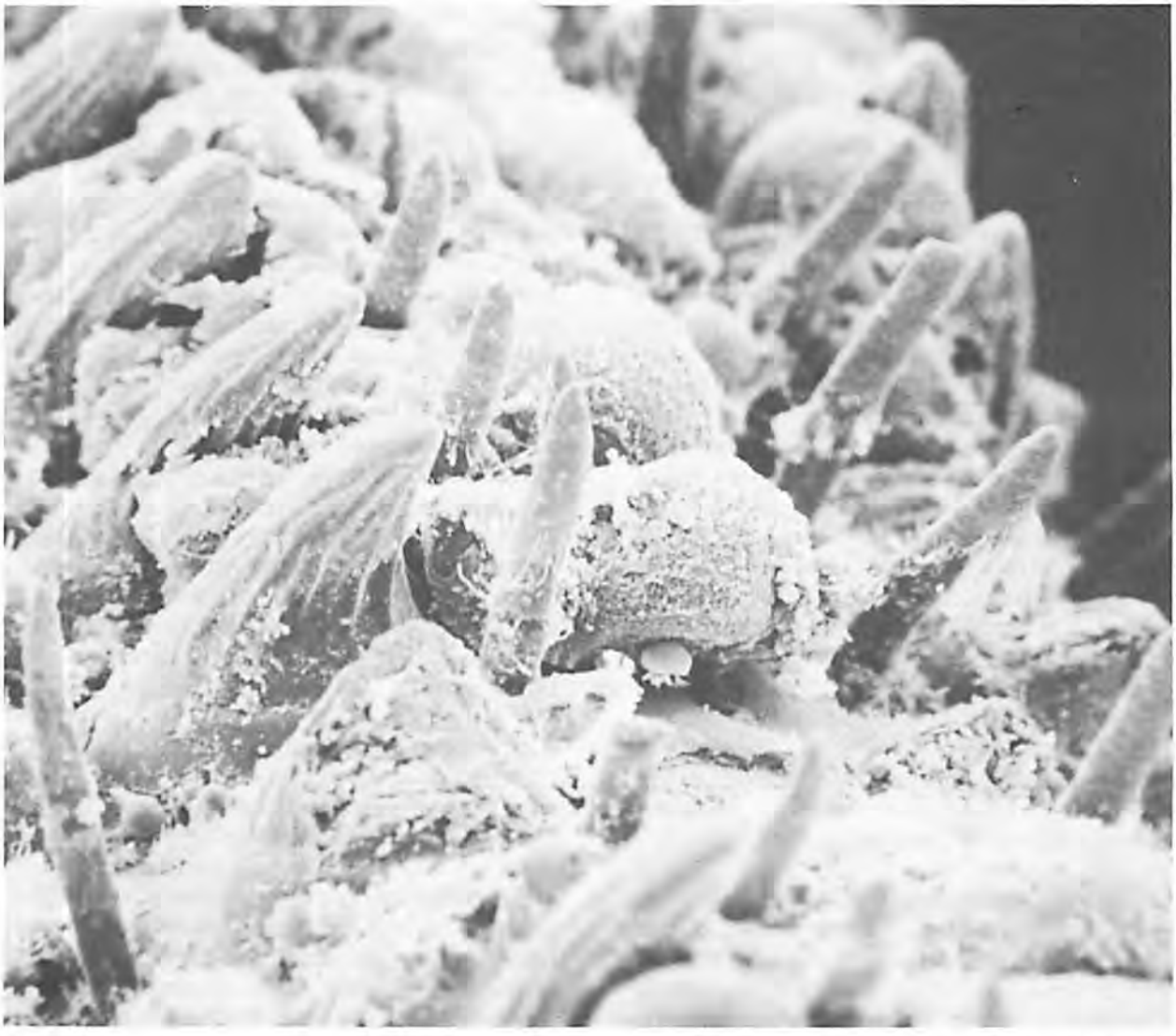

Figure 1. Scanning electron micrograph showing small part of dactyl of a kelp crab, *Pugettia*. Narrow, chemoreceptive setae are seen primarily in two rows, with conical, nonsensory spines laterally to them. Smoothly rounded lumps of tar are seen throughout the receptor field.

vicinity of a petroleum seep such as Coal Oil Point frequently reveals tar accumulated on the integument in close proximity to chemoreceptor setae. Figure 1 shows the dactyl surface of a kelp crab, *Pugettia*, which was collected in good condition even though peppered with tiny tar balls. This specimen was shown electrophysiologically to still possess normal dactyl chemoreceptors. Such animals may, of course, only be the survivors of populations more susceptible to petroleum. Electro-physiological tests on crabs (dactyl contact, or taste, receptors) and lobsters (dactyl and antennular olfactory receptors) do show some direct effects of water-accommodated petroleum fractions, especially upon antennular receptors. Although not proved by direct experimentation, these latter tests leave open the possibility that subtle chemosensory orientation such as olfactory tracking of food or conspecifics may be disturbed.

In field tests conducted to date, kerosene-soaked bricks were used in traps alone or along with standard abalone bait. Kerosene + abalone fished as well as abalone alone, while kerosene alone was not significantly more effective than unbaited traps. Since we do not know with certainty, under the field conditions maintaining in our trapping grid, if lobsters locate baited traps by olfactory orientation--as opposed, to name one possibility, to random wandering plus near-field (or taste) search when a trap is accidentally approached--these results do not remove petroleum from suspicion.

In searching for a way to directly and more easily detect chemosensory arousal that might not be evident as immediately observable behavior, we used the noninvasive technique of Doppler electrocardiography to monitor excitation of gill activity chemoreceptors by means of the transient bradycardia that they induce when excited. This method demonstrated the presence of amino-acid-sensitive receptors in the gill cavities of both the kelp crab and spiny lobster. These are sufficiently sensitive to suggest that they may play an olfactory role in food search, and they are found to be sensitive to water-accommodated petroleum fractions.

Field Studies on Natural Baits

Extensive tests using either a 3 x 5 trap matrix or eight paired trapping stations provided clear evidence regarding relative attractiveness of natural baits, the effects of bait age, and the most economical quantities of bait. Abalone and ground mackerel were equally effective in trapping lobsters, and relatively ineffective in trapping crabs (*Cancer*).

Angel shark (*Squatina californica*) was attractive to crabs (*Cancer antennarius, Loxorhyncus grandis*) and swell shark (*Cephaloscyllium ventriosum*), but not to lobsters (table 1). Sea urchin (*Strongylocentrotus*) and shrimp (*Sicyonia ingentis*) cephalothoraxes failed to attract lobster, crabs, or swell sharks. We experimented with abalone to determine the influence of bait age and quantity. Bait aged one to two days in seawater attracted significantly more lobsters than did fresh bait. As little as 7 to 10 gms, with a mean weight loss of .09 gm/hr, effectively captured lobsters (table 2). This suggests that the effect of the bait may be to arouse random search activity rather than to induce classical odor stream following. It is deemed unlikely that simple orientation up chemical gradients could be possible, considering the low effective concentration of stimulants and the agitation of the water at the shallow depth of the trap array.

Table 1
Specificity of
Abalone and Angel Shark as Baits

Species	Abalone (*Haliotis* sp.)	Angel shark (*Squatina californica*)	X^2 value	sig. level* (p)
Panulirus interruptus (lobster)	50**	23	9.99	<0.005
Loxorhyncus grandis (sheep crab)	7	18	4.84	<0.05
Cancer antennarius (rock crab)	11	35	12.52	<0.001
Cephaloscyllium ventriosum (swell shark)	3	17	9.80	<0.005

*All significance levels were determined by a chi-square (Goodness-of-fit) test, with one degree of freedom. Expected values do not appear in the table, but were generated to represent a 1:1 ratio between the number of animals captured with abalone vs. the number captured with angel shark.

**Number of animals captured

Bait Fractionation Study

Abalone scraps, as used for lobster bait, were lyophilized. Molecular weight fractions were prepared by ultrafiltration. The initial material and the various subfractions were analyzed by ion exchange amino acid analysis. Subfractions and amino acid mixtures, prepared on the basis of the determined amino acid composition of the tissue, were prepared for laboratory behavioral assay and for field trapping tests by binding in a polyacrylamide gel. In some experiments crude oil was added to the gels. Under laboratory bioassay conditions the test

Table 2
Influence of the Quantity of Abalone Bait on Lobster Capture

Bait mass (gms) $\bar{x} \pm$ s.e.	Total number captured (*abalone* versus unbaited traps) Day[a] 1	2	Day[b] 3	4	Total	Bait dissolution rate (gms/hr) $\bar{x} \pm$ s.e.	Water-flow index values $\bar{x} \pm$ s.e.
372 ± 6	*15*-2[d]	*21*-0	*19*-0	*22*-3	*77*-5*	3.8 ± 0.2	0.53 ± 0.02
176 ± 4	*11*-0	*13*-1	*30*-2	*16*-1	*70*-4*	2.7 ± 0.3	0.55 ± 0.04
93.96 ± 2.29	*41*-1	*23*-0	*7*-0	*16*-0	*87*-1*	2.02 ± 0.08	0.56 ± 0.02
46.71 ± 0.45	*6*-2	*23*-2	*27*-0	*23*-1	*79*-5*	0.64 ± 0.03	0.51 ± 0.01
18.44 ± 0.16	*17*-3	*13*-1	*7*-0	*10*-0	*47*-4*	0.28 ± 0.01	0.56 ± 0.01
7.20 ± 0.12	*4*-4	*9*-3	*8*-1	*0*-1	*21*-9*	0.09 ± 0.01	0.51 ± 0.01
2.61 ± 0.06	*0*-0	*1*-3	*1*-1	*2*-1	*4*-5	0.03 ± 0.00	0.58 ± 0.04

[a]Trapping days 1 and 2 paired, and bait-positioning reversed. Descending order of bait-quantity presentation.
[b]Trapping days 3 and 4 paired, and bait-positioning reversed. Randomized order of bait-quantity presentation.
[c]Water flow index values, for days on which different bait-quantities were tested, did not differ significantly (1-way ANOVA, with replicates: d.f. = 6/21, $F = 1.55$, $p > 0.10$).
[d]The number of lobsters captured by abalone baited traps is printed in italics.
*The difference between the total number of lobsters captured by baited versus unbaited traps was significant (Chi-square Goodness-of-fit test, 1:1 expected ratio, d.f. = 1, $p < 0.05$).

fractions and artificial mixtures were also tested as free solutions. We initially expected that the effective component would be the low molecular weight fraction. In fact, the major activity lies between 1000 and 10,000 daltons. Of this, the 70% ethanol insoluble portion, presumably mostly protein and peptide, contains nearly all of the activity. Field tests are incomplete, but so far indicate that no bait fraction is as active as the initial lyophilized material.

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Cooperating Organizations

Department of Energy
University of California Cooperative Extension

Assessment of Aging Techniques and Their Application to Elasmobranch Fisheries

Moss Landing Marine Laboratories
R/F-57
1979-80

Gregor M. Cailliet

Utilization of elasmobranch fishes from California waters is increasing at a tremendous rate. Historically, sharks were used for their oils and for reduction purposes (Byers, 1940), for the vitamins in their livers (Frey, 1971), and as a human food (Frey, 1971; Hart, 1973). Their use as a human food is rapidly gaining favor.

A major problem that arises with this increased use of elasmobranchs is that very little is known of life history characteristics that would be essential to their effective management. For example, age determination has not been evaluated sufficiently for most California elasmobranchs, and, therefore, age at first reproduction is not known. Since the usual means of aging fishes--by examining scales, otoliths, or bones--are not applicable to elasmobranchs, it has been thought that they cannot be easily aged (Stevens, 1975; Holden, 1977). However, the evidence that does exist indicates that growth rates are slow, and time to sexual maturity is very long--estimated, for example, at about nine years for *Galeorhinus zyopterus* (Holden, 1977) and for *Raja clavata* (Steven, 1936), and fourteen to twenty-three years or longer for *Squalus acanthias* (Ketchen, 1972, 1975; Holden, 1973; Holden and Vince, 1973; Jones and Geen, 1977a). First reproduction occurs relatively late in life, and fecundity is low (Holden, 1973, 1974, 1977; Jones and Geen, 1977b). Fishing the premature early life stages can deleteriously affect the total population size quickly, especially in elasmobranchs, since stock and recruitment are more closely related than in teleostean fishes. The age and size at which first reproduction occurs is information that is vital to fishery management.

The approach to this project has been twofold. During the first year, we have tested five aging techniques, using vertebrae collected from common Californian elasmobranchs, to determine which technique is applicable to specific species and which has the widest applicability and highest accuracy. In the second year, once these methods have been determined, we will apply them to as many commercial and potentially commercial elasmobranchs as possible from California waters. Specimens for this part of the study will be from our own field collections and from sampling the commercial catch in several ports, a task in which we have already been involved.

Resulting methods that improve our ability to age elasmobranchs and to determine their age- and size-specific reproductive habits will increase management capability for this emerging resource.

Progress to Date

1. We have experimented with cleaning, slicing, and grinding procedures to prepare vertebrae for subsequent aging, and have found that the amount and type of work necessary differ considerably among different species. We have used five methods of exposing the rings for counting, including silver nitrate impregnation (Stevens, 1975), radiography (see figure 1),

Figure 1. Radiographs of vertebrae from two species of elasmobranchs.
(Top) Bonito shark (*Isurus oxyrinchus*) 173 cm total length; centrum diameter 22 mm.
(Bottom) Pacific angel shark (*Squatina californica*) 65 cm total length; widest centrum diameter 11 mm.

formic acid etching, cedarwood oil clearing, and Alizarin red staining.

Different ring counting methods work best with different species, and no one technique works best for all. We have prepared vertebrae and counted their rings in 25 skates, 143 bat rays, 35 angel sharks, 40 leopard sharks, 40 smoothhounds, and 10 bonito sharks. When more data are analyzed, we will produce growth curves for these species. Some species, such as the bonito shark, appear to be relatively short-lived, while others, such as the angel shark, look more long-lived (figure 1).

2. In order to correlate growth data with maturity, we have had to develop qualitative, descriptive techniques to assess reproductive state, and more quantitative techniques to evaluate features like fecundity in females and sperm maturation in males. We will eventually combine this reproduction data with our growth curves to provide age- and size-at-first-reproduction information for as many California species as possible.

3. We have made contacts with the U.S. National Marine Fisheries Service at Tiburon, California, and with Steinhart Aquarium, San Francisco, for collaborative grow-out studies; these studies are under way. They are necessary to verify that the rings we count are annual.

4. We have sampled from central California to Baja California to obtain specimens for aging. We also have dissected elasmobranchs from several shark derbies and from commercial fishing vessels. A total of 75 days of sampling has provided over 700 specimens, representing at least 25 species. Vertebrae from these specimens are frozen, and morphological, environmental, and reproductive information on them is stored in our reference files. In addition, we have removed ovaries for later egg counts and have made stained sperm smears for maturity estimates of over 250 sharks. We will increase our efforts in this area. Finally, we have been in touch with individuals from numerous institutions, especially in southern California and Mexico, in order to collect more specimens from all along the California coast.

5. Information about our activities has been disseminated primarily through our contacts with potential sources of specimens, including personnel of the California Department of Fish and Game, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the California Academy of Sciences, several commercial fisherpeople in various locations along the coast, and private environmental companies such as Kinnetic Laboratories, Inc., the Southern California Coastal Water Research Project, and Pacific Bio-Marine. In addition, we have been in touch with ichthyologists from many state and private colleges and universities, and all of the California Sea Grant Marine Advisors.

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Cooperating Organizations

Cabrillo Museum, Long Beach
California Department of Fish and Game
National Marine Fisheries Service
Sea Grant Marine Advisory Service
Several southern California fishermen's associations
Steinhart Aquarium
U.S. Fish and Wildlife Service

Multiple Species Utilization of the Herring Eggs-On-Seaweed Fishery

Stanford
R/F-58
1979-80

Isabella A. Abbott and Judith E. Hansen

The red alga *Gracilaria verrucosa* (Hudson) Papenfuss is a primary source of the phycocolloid agar. The colloid is used by numerous food industries for its unique gelling properties, but its greatest and most critical use is as the base for culture media. Agarose is derived from agar and is used when a highly purified gel is required. The price of bacteriological-grade agar has risen sharply in the past four years to $125/kg (DIFCO catalog, 1980), and food-grade agar is about 40% of this cost. Agarose costs $230 to $750/kg, depending on its purity (Marine Colloids of FMC price list, 1978). Its use is specialized, and more colloid is needed than is available.

In addition, *Gracilaria*, among other algae, is commercially harvested from Pacific coastal bays during winter for the herring eggs-on-seaweed fishery. The algae and attached eggs are salt cured and exported to Japan, where they are considered a delicacy. The highest-quality product retails for about $20,000/ton (eggs-on-seaweed, salt cured).

A multifaceted problem exists here: new and stable sources of domestic agarweed are needed, and the herring eggs-on-seaweed fishery must rely on an unpredictable *Gracilaria* crop that may senesce during winter. Our approach to the overall problem is to integrate the two fisheries through the development of *Gracilaria* mariculture. *Gracilaria* grown under mariculture conditions could provide a stable, high-quality substratum for harvesting eggs-on-seaweed during winter. For the remainder of the year, cultivated *Gracilaria* could be harvested as an agarweed resource. Physiological studies on *Gracilaria* productivity and senescence will provide supportive data necessary to evaluate the *Gracilaria* resource.

Development of *Gracilaria* mariculture to provide a domestic agarweed resource and a base for enhancing the seasonal herring eggs-on-seaweed fishery requires a firm biological foundation regarding the alga and phycocolloid under study, and a detailed assessment of the herring eggs-on-seaweed fishery. Our objective--integrating the two unique, yet clearly intermeshed fisheries--involves a study on management of biological timing. Herring spawn only in winter, during which *Gracilaria* acts as a substratum and would, therefore, be harvested with that fishery. For the remainder of the year *Gracilaria* could serve as an agarweed resource.

In this first year of the project we have focused on *Gracilaria* and herring field studies as well as on methodology for *Gracilaria* mariculture.

The autumn-winter (1979-80) field studies of herring spawning activities and vegetational analysis in Elkhorn Slough was cosponsored by, and done in collaboration with, California Department of Fish and Game. Vegetation maps of major *Gracilaria* populations within the slough and harbor area were prepared in autumn and following storms in winter. Herring spawning activities were assessed at seven stations from 18 December 1979 to 1 March 1980, using established techniques (Miller and Schmidtke, 1956; Hardwick, 1973).

The vegetation assays showed that the *Gracilaria* populations suffered a heavy loss in biomass following winter storms (figure 1). Results provide the first documentation of herring spawning activities in Monterey Bay. Herring eggs were recorded on *Gracilaria* from 17 January to 28 February 1980 only at the junction of the harbor and Elkhorn Slough (Stations 1, 2, 3). Herring eggs-on-*Gracilaria* was considered light to moderate by commercial standards (Calif. Fish and Game, Hardwick, pers. comm.).

Field studies of the experimental *Gracilaria* population (figure 1, Station 4) were initiated in December 1979. Standing crops (control biomass) have been determined for four seasons. We also determined the effects of a winter harvest on subsequent regrowth (experimental). In addition, biomass was harvested at the beginning and at the end of each season to determine discrete, seasonal regrowth using established methods (Hansen, 1977). The results (figure 2) indicate a major loss in

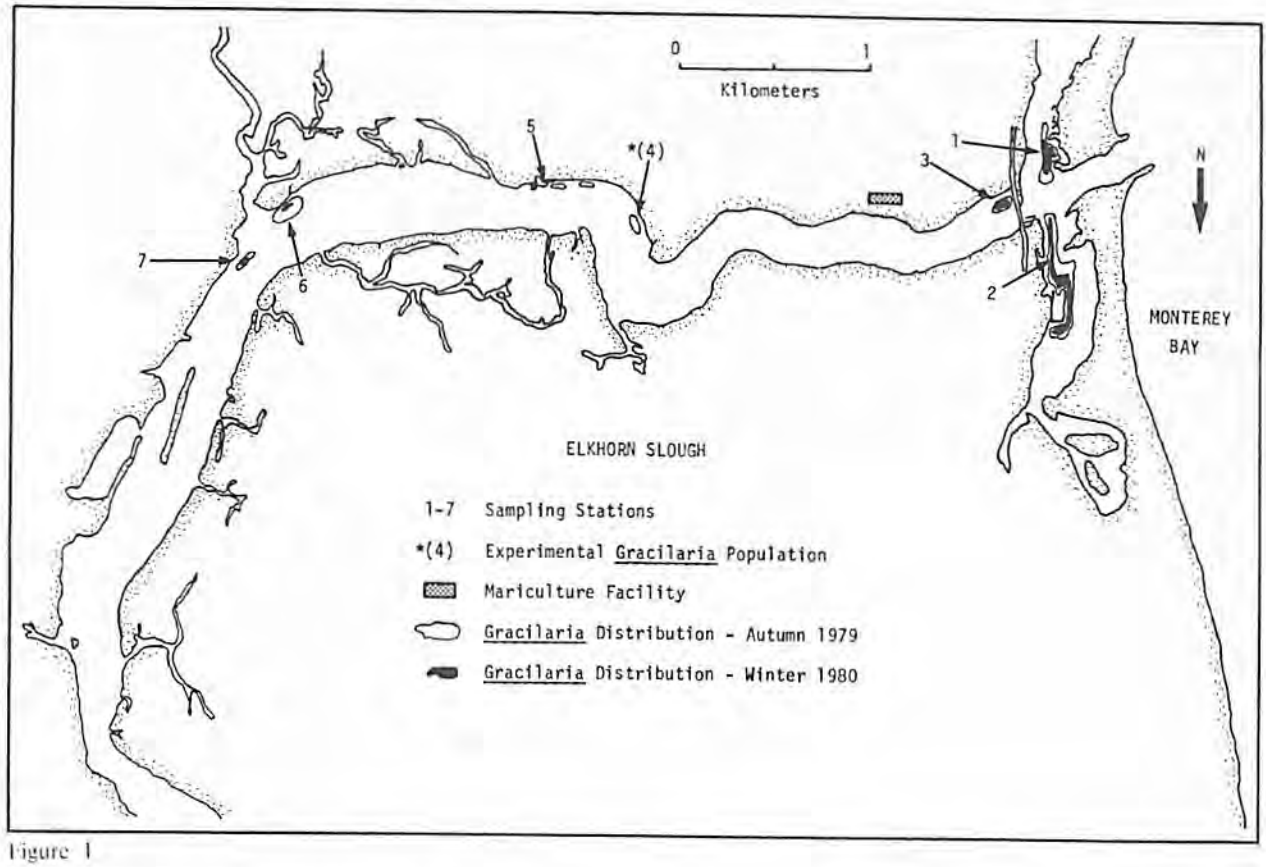

Figure 1

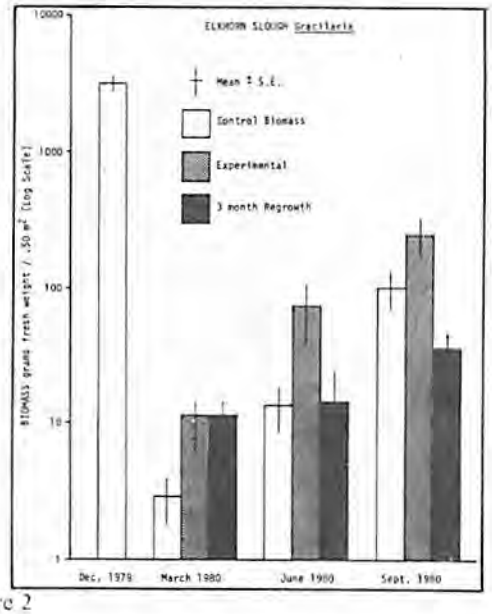

Figure 2

biomass during winter followed by slow regrowth. In autumn (nine months later), both the control and experimental populations had attained only 10% of the original biomass. A single winter harvest appears to have no significant effect on regrowth to date.

A 30.5 m x 9.2 m earthen enclosure adjacent to Elkhorn Slough was used as an experimental *Gracilaria* mariculture facility. Slough waters were pumped continually through the facility. Techniques were established for growing *Gracilaria* on monolines. Specific growth rates varied from 10%/day^{-1} to 4%/day^{-1}, depending on the initial stocking density of the *Gracilaria* inoculum (bundle) on the line (10 gFW to 300 gFW, respectively). Calculated production rates vary from 1 to 12 gFW/bundle/day.

An experimental *Gracilaria* crop has been planted on monolines and grown out in the culture facility. This crop was moved to Elkhorn Slough for pilot testing, and will be transplanted into San Francisco Bay for the 1980-81 herring spawning season.

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Cooperating Organizations

California Department of Fish and Game
Marine Bioassay Laboratory (Watsonville, California)
Marine Colloids of FMC (Rockland, Maine)

Improved Marine Food Products and Marine Food Technology

UC Davis
R/F-32
1978-80

W. Duane Brown

This project was intended to provide new or altered technology to improve quality in seafood products, resulting in products that are more appealing for the consumer and that retain maximum nutrition. A primary objective was to study and improve methods of packaging and handling for a variety of seafood products in the hopes of extending distribution of fresh and frozen seafoods.

Use of Modified Atmospheres with Seafood Products

It has long been known that high levels of carbon dioxide (CO_2) inhibit microbial growth and make possible prolonged storage of fish. However, the application of this technology has not received a great deal of attention. We held salmon steaks and rockfish fillets in atmospheres of CO_2 up to 40%, and performed microbial, chemical and sensory analyses at varying time intervals. The results showed that storage under CO_2 reduced the formation of the spoilage products trimethylamine and ammonia, and markedly inhibited microbial growth.

However, it was clear from the early work that higher levels of CO_2 might even be more effective, and this led into substantially more detailed work with fresh rockfish fillets. Samples were held either in air or in atmospheres containing 80% CO_2: 20% air for extended periods (up to 14 days) in refrigerated storage. Samples of fillets from each treatment group were removed at various intervals and subjected to chemical and microbial analyses. There was a drastic inhibition of microbial growth in the modified atmosphere samples (see figure 1). In contrast, samples stored in air showed marked growth at 7 days, continuing upwards throughout a 14-day period. Slime and decaying odor were very perceptible in control samples after 10 days; there was no slime or off-odor in samples stored in modified atmospheres after 14 days. Surface pH increased from 6.7 to 7.5 in control samples, while the treatment group showed values decreasing from 6.7 to 6.3. The reason for the effectiveness of carbon dioxide is not known, but may in part be associated with the change in pH. Samples held in modified atmospheres also showed significantly less accumulation of trimethylamine (figure 2) and maintained higher surface oxidation-reduction potentials than did the controls.

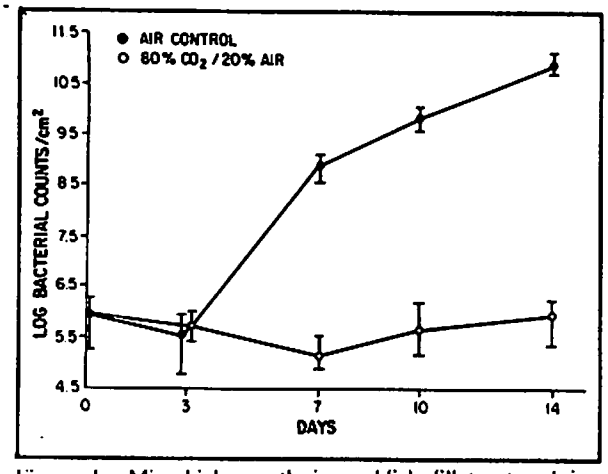

Figure 1. Microbial growth in rockfish fillets stored in modified atmospheres versus that in controls stored in air.

A similar study was done with cooked Dungeness crab, with similar findings. Samples could be stored for well over a month under CO_2 without deteriorative changes of a microbial or chemical nature. After about two weeks, however, there was a slightly "acidic" taste in

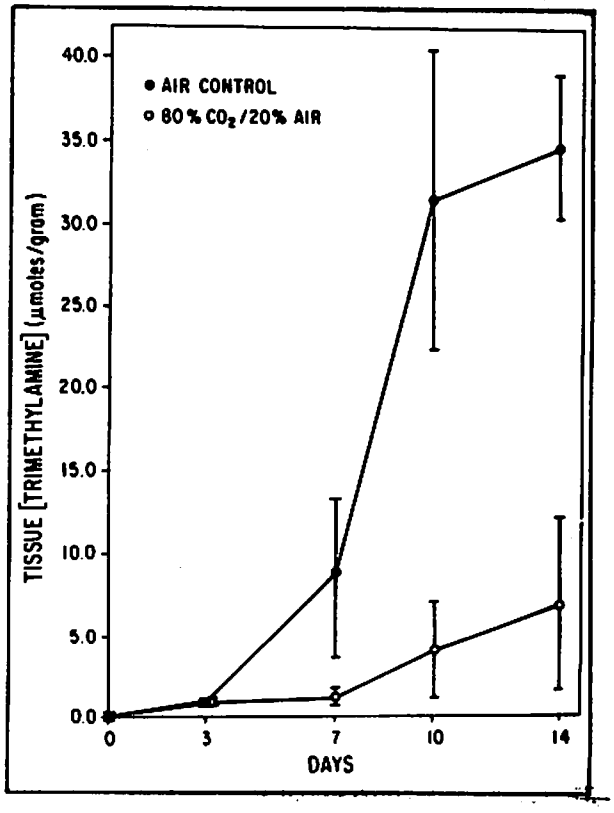

Figure 2. Production of trimethylamine in rockfish fillets stored in modified atmospheres versus that in controls stored in air.

the samples stored in modified atmospheres. This was presumably associated with the dissolution of CO_2 in muscle tissue. Steaming the crab eliminated this off-flavor.

One of our trainees conducted field studies with modified atmospheres in Alaska. He was able to demonstrate the effectiveness of modified atmosphere in retarding spoilage of dressed gray cod, gray cod fillets, Alaskan spot shrimp, and halibut steaks. Commercial shipments of whole salmon held in modified atmospheres have also been made. In these cases, fish were shipped refrigerated (not frozen) from Anchorage to Seattle by steamship in Sea Land vans treated by TransFresh personnel to contain 65% CO_2. There were no losses from spoilage, and economic considerations appear promising (table 1).

The use of modified atmospheres raises the question of possible changes in microflora on products held under such conditions. We have done some preliminary work in this area, using both filleted and minced rockfish (sold in California also as red snapper) and so-called short-bellied rockfish. Gram negative bacteria in general, and the major aerobic spoilage bacteria found in fish in particular (*Pseudomonas* and *Acinetobacter/Moraxella*) species, were inhibited by modified atmospheres containing 80% CO_2:20% air. Gram positive bacteria in general, and lactic acid bacteria in particular, were selected for and grew readily under the high level of CO_2. However, the growth rates of the latter organisms were still low, and products were stable for long periods of time.

Other studies showed that minced fish (rockfish, as mentioned above, plus English sole)--if prepared from fresh products, placed under modified atmospheres, and kept refrigerated--remained highly palatable. In cooperation with colleagues at the University of Nebraska we were able to show that protein quality was maintained better in salmon stored in modified atmosphere than in air, or canned under usual commercial conditions.

Histamine Toxicity from Fish Products

This project completed earlier research done on project R/F-22. A great deal of work was done to develop various bioassays for histamine. Newly hatched Japanese quail were found to be sensitive to the addition of histamine to chick starter meal and to toxic tuna. The small crustacean *Daphnia magna* was also found to be sensitive to histamine, and the ease of assay with this organism suggests potential for its use in quality-control testing. We also studied a number of large animals, including pigs, cats, dogs, and rabbits. Young pigs were the only animals showing a reaction to toxic fish.

Table 1
Costs for Refrigerated Shipment, Anchorage to Seattle

Mode of Transportation	Costs, Cents per Pound
Air freight	15 to 40
Steamship, no atmosphere treatment	3.05 to 4.00
Steamship, modified atmosphere treatment	4.30 to 5.25

Myoglobin Pigments in Fish

Oxidation of myoglobin is responsible for one of the major colorations found in fish and is a problem in some heavily pigmented fish stored in modified atmospheres. Consequently, we have made detailed studies of this protein from fish sources, particularly myoglobin from yellowfin tuna. We have determined the complete amino acid sequence of this myoglobin. This is the first myoglobin for which this detailed information is known. There are significant differences in amino acid substitutions in this myoglobin compared to those in mammals and birds. Some of our work has explored possible consequences of these changes in the role of fish myoglobin. As part of this work, and in cooperation with Dr. Lou Hagler of the Letterman Army Research Institute, we are working with a recently discovered enzyme, metmyoglobin reductase, to determine how metmyoglobin reduction differs in marine species compared to mammalian species. Metmyoglobin formation causes darkening of fish muscle, resulting in an unacceptable color. A better understanding of the enzyme that reconverts metmyoglobin to the desirable red color of oxymyoglobin may lead to the development of better storage and handling for certain seafood products.

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Cooperating Organizations

Letterman Army Research Institute (Dr. Lou Hagler)
National Fisheries Institute
Tarantino Seafoods
TransFresh Corporation
University of Nebraska (Prof. L. Satterlee)
Wayne State University (Prof. A. Romero-Herrera)

Design and Development of a Squid Processing Machine

UC Davis
R/F-33
1978-80

R. Paul Singh, R.J. Coffelt, and D.E. Brown

Squid is an important source of protein in many countries, particularly in the Orient and Mediterranean Europe. The current world catch is estimated at a half million tons, and it may be possible to sustain a fishery of over one hundred million tons annually.

Despite squid's excellent food value and mild flavor, there is virtually no market for it in North America. The appearance of whole squid makes it unappetizing to many in the marketplace despite its relatively low retail price ($.69 to $.99/lb). The average consumer does not know how to clean or prepare whole squid. Seafood restaurants serving squid find the demand low and the hand-cleaning costs high. (Hand cleaning adds $1.50 to $2.00/lb. to the price of squid for the restaurateur.) Prepared foods made from cleaned squid meat have been well received in preliminary tests, and this shows that there is a potential market for squid in this country.

One species of squid abounds off the coast of California, *Loligo opalescens* Berry (California market squid). Current methods for processing squid by the California fishing industry involve much hand labor. The high labor costs of hand cleaning limit squid's use to small-scale special-order vendors. Cleaning involves removing the head, eyes, skin, viscera, ink sac, and backbone from the body (mantle). This leaves a white flesh cone, which can be split into a fillet. The tentacles are saved intact. There have been no mechanical cleaning systems available. The development of an industrial-scale machine for economical cleaning of squid could revolutionize this industry. In this project we have developed an automatic squid-cleaning machine and another machine to feed squid into it.

Design Considerations

Information on squid anatomy and morphology was utilized in the design of this machine. The cleaned body, called a mantle, resembles a hollow, flexible cone (figure 1). The body wall thickness is 3-5 mm (0.1 - 0.2 in). This conical shape is used in the alignment, ducting, skinning, and gutting processes of the machine (figure 2).

The elongated, conical shape of the squid mantle facilitates its ducting from the alignment trough to the skinning/evisceration peg. The mantle is firm enough to remain oriented longitudinally in a close-fitting duct, and can be transported by gravity or with the aid of moving water over any distance required.

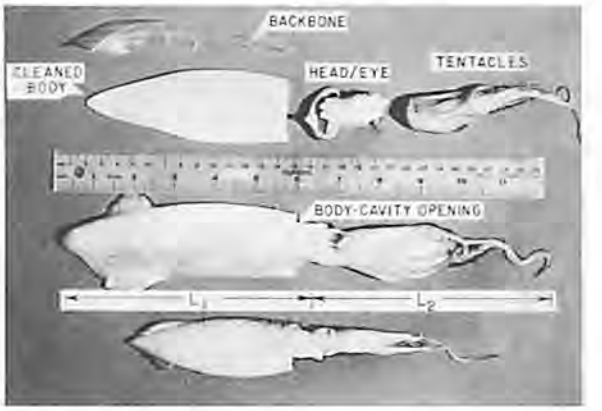

Figure 1

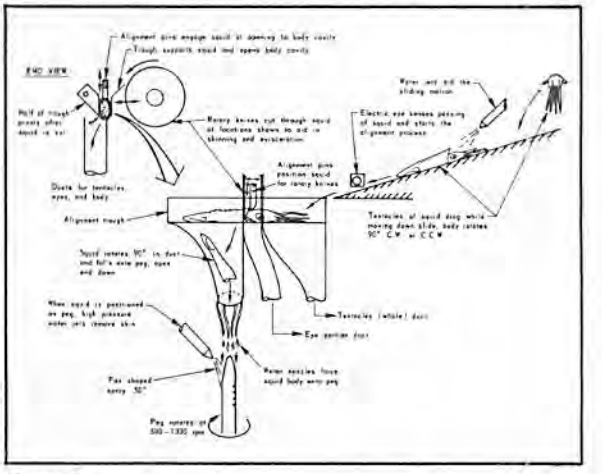

Figure 2

The hollow, conical shape of the body then provides a means to hold the squid for the skinning process. The squid bodies are ducted onto a rotating peg (figures 2 and 3). The viscera, attached to the dorsal side of the squid body interior, are displaced to one side as the squid slides onto the peg. The mantle assumes the rotation of the peg, 400-1000 rpm, and rotates along its major axis below the skinning water jets. The body-cavity is kept open and circular as it is ducted onto the peg by a flexible-tube water-jet funnel.

One nozzle, producing a fan-shaped water spray, is all that is required to skin the squid. The squid body receives an even blast of water as it rotates under the skinning nozzle. The fins

are sheared from the body by the nozzle and are propelled out and away from the rotating peg. The fins drag much of the skin off with them because of the skin's firm attachment at their edges. The remainder of the skin is peeled down the length of the body by the downward blast from the water nozzle.

Evisceration, ink sac removal, and backbone (pen) removal are accomplished by water jets in the rotating peg (figure 3). A pair of clamps closely matching the conically-shaped squid exterior engage the squid body to stop its rotation and support it for evisceration. The rotating peg's water jets sweep past the interior of the squid, giving an even 360° coverage, shearing off the viscera and membranes holding the backbone. The viscera are flushed out the open bottom of the squid body. The viscera, skin, and backbones are collected in a large pan under the machine. The cleaned squid bodies are then propelled off the peg and out of the machine by a ring of water jets at the base of the skinning/evisceration peg (figure 4).

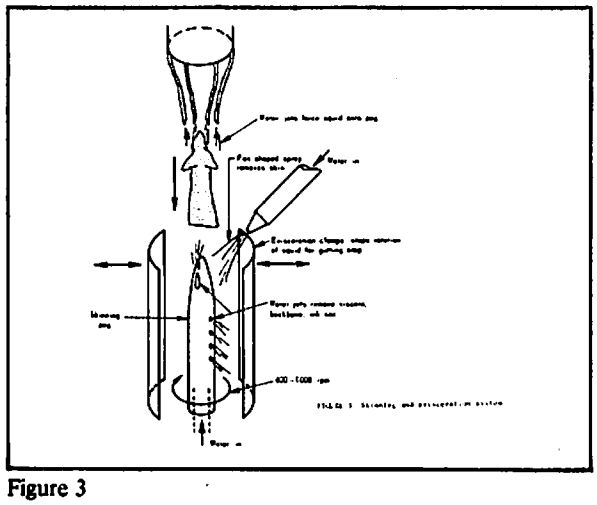

Figure 3

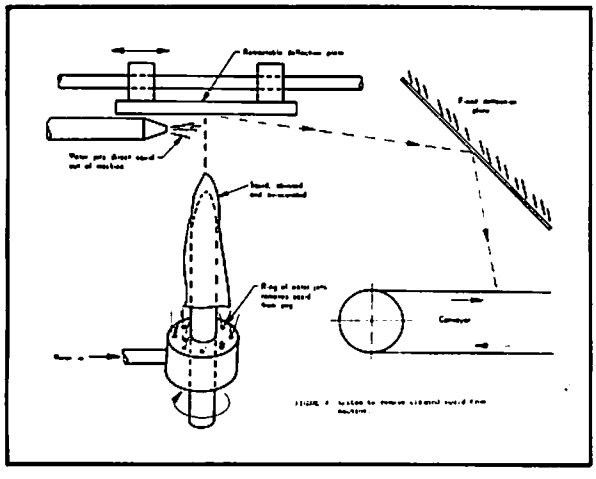

Figure 4

Our pilot-scale squid processing machine is fully automatic. The control system for its various functions is activated by an electric eye. Fifteen seconds is required to produce a cleaned squid, yielding a clean white mantle. With a two-stage operation the processing time could be cut in half.

Results and Discussion

We conducted a variety of tests of the machine, using both fresh and frozen squid. Yield by weight of hand-cleaned squid generally ranges from 50% to 55%. The yield by weight of the pilot-scale machine is comparable with a hand-cleaned operation. The frozen squid sample averaged 45%, and the unfrozen sample 52% of edible meat return. The yield is dependent on initial size of individual squid processed and prior handling. The processing efficiency was highest on squid with bodies 110-150 mm long, 72% of the catch by weight. The pilot-scale machine forms the basic unit around which an industrial-scale squid processing machine could be built. The pilot-scale machine's processing rate is 4 squid/min., 40 lbs/hour.

For the second part of our project, we built and tested a machine to align and separate squid for automatic feeding to the squid-cleaning machine, or for packaging.

The technique we developed is shown in figure 5. Squid are circulated in a holding tank by water jets, which also separate the squid and direct them through ducts to an alignment slide. The squid slide down the alignment ramp and are oriented mantle first as they enter the squid cleaning machine. The average rate to align and separate 60 squid for the cleaning machine was 2.1 squid/sec. Under continuous operation the efficiency of the system reached a level of 92%. Squid were aligned at a 71% level. This device could automatically feed 15-17 squid cleaning machines of the type already developed.

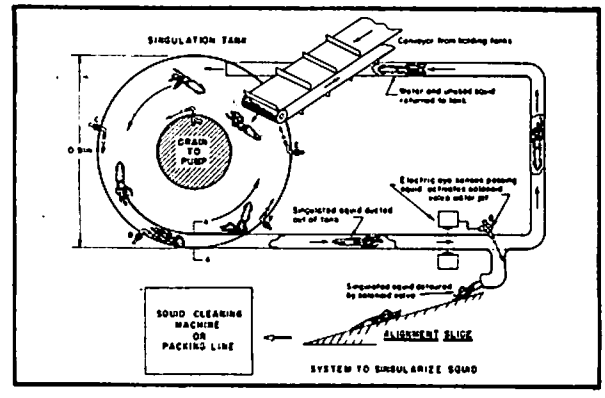

Figure 5

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Cooperating Organizations

Sea Grant Seafood Advisory Committee

Genetic Improvement of a Chitinase-Producing Microorganism

UC Davis
R/F-50
1978-80

David M. Ogrydziak

The major aim of this project was the genetic modification of *Serratia marcescens* in order to isolate mutants that produce increased levels of chitinolytic activity.

Chitin is an unbranched polysaccharide composed primarily of β-1,4 linked N-acetylglucosamine residues with occasional glucosamine residues. Chitin is the principal structural component of insect exoskeletons and of crustacea such as shrimp and crab. The processing of these shellfish generates a waste-disposal problem, and chitinase is essential to a bioconversion process in which waste shellfish chitin is enzymatically hydrolysed to N-acetylglucosamine, which in turn is assimilated by an edible yeast (Carroad and Tom, 1978.) The cost of the chitinase would be a major factor in the overall cost of the bioconversion process, so a chitinase overproducing strain would increase the economic feasibility of the bioconversion process.

A microbial source of chitinase was sought, and *Serratia marcescens* QMB1466 was chosen since it was one of the most active chitinase producers of the 400 chitinolytic fungi and bacteria tested (Carroad and Tom, 1978; Monreal and Reese, 1969). The chitinase system of *S. marcescens* resembles that of most chitinolytic eucaryotes and procaryotes in that chitin is hydrolysed to N-acetylglucosamine by two separate hydrolases: (1) an endochitinase that produces low molecular weight, soluble multimers of N-acetylglucosamine, the dimer N, N'-diacetyl chitobiose being predominant, and (2) a chitobiase that hydrolyses the intermediates to N-acetylglucosamine. The *S. marcescens* chitinase system differs from many other chitinolytic systems that act only on swollen chitin in that it includes an additional factor (CH_1) required for the hydrolysis of "crystalline" chitin.

First, we confirmed that in our hands *S. marcescens* QMB1466 produced levels of chitinase (0.292 U/ml of supernatant) comparable to those reported in the literature (0.283 U/ml) by Monreal and Reese. One unit of chitinase activity equals 1 μmol of reducing sugar released per minute. The assay involved shaking swollen chitin at 50°C for one hour in the presence of enzyme.

Then over 14,000 survivors of UV mutagenesis were screened on chitin-containing agar plates (NAC) for chitinase production (table 1). Isolate IMR-R1 was chosen from the UV mutagenesis step, and it was mutagenized with ethylmethane sulfonate (EMS). Isolate IMR-1E1 was obtained, and produced a much larger zone of clearing than IMR-R1 and QMB1466. It also overproduced chitinase in minimal plus chitin (M9C) medium (table 1). One round N-methyl-N'-nitroso-guanidine (NTG) mutagenesis was done, but no isolates outproducing IMR-1E1 were obtained.

Table 1
Mutagenesis and Selection of Strains of *S. marcescens* That Overproduce Chitinase

Step	Mutagen	Parental Strain	Number of Exp.	Survivors Plated
1	UV	QMB1466	8	14,763
2	EMS	IMR-R1	3	4,148
3	NTG	IMR-1E1	1,029	

[a]Assayed using the agar diffusion assay on supernatants from M9C (without yeast extract) shake flask cultures. Wild type chitinase production was 0.21 U/ml.

Isolates Screened on NAC Plate	Isolates Screened in Shake Flasks	Isolates	Chitinase Production of Isolate[a] (units/ml)
615	39	IMR-R1	0.31
300	3	IMR-1E1	0.44
100	2	IMR-NTG1	0.37

Strains QMB1466, IMR-R1, and IMR-1E1 were compared for maximum chitinase production. Figure 1 shows the chitinase activity of culture supernatants sampled over several days of growth in Reese medium without yeast extract. The maximum chitinase activity of strain IMR-1E1 was 0.483 units/ml, which was 2.7 times the wild type level in this experiment. In Reese medium with yeast extract, the maximum chitinase activity of strain IMR-1E1 was 0.592 units/ml, which was about twice the normal wild type activity. However, in M9C medium mutant IMR-1E1 produced 3.3 times as much chitinase in 24 hours as the wild type produced in 3 days (data not shown).

In Reese medium the wild type yields 2.0 times more cells. On a per cell basis, strain

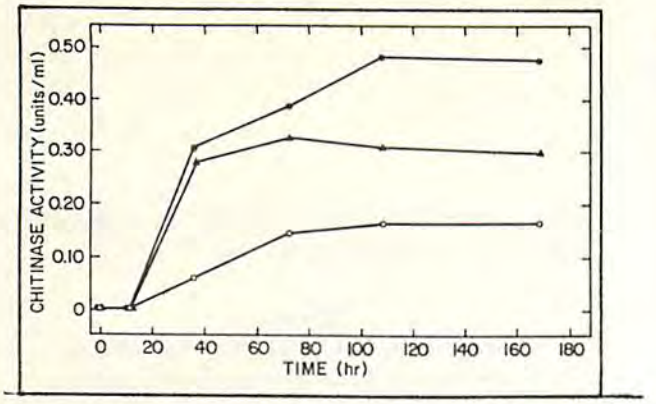

Figure 1. Time course of chitinase production. Cells were grown in Reese medium (pH 7.5) without yeast extract. The inocula were grown in LB medium and therefore were not induced for chitinase. The number of cells in the shake flasks following inoculation was: QMB1466 (wild type), 2.1×10^7 cells/ml; IMR-R1, 1.9×10^7 cells/ml; and IMR-1E1, 1.1×10^7 cells/ml. The number of cells during stationary phase was: QMB1466, 7.0×10^9 cells/ml; IMR-R1, 3.4×10^9 cells/ml; and IMR-1E1, 1.4×10^9 cells/ml. Chitinase activity of strains QMB1466 (0), IMR-R1, (Δ) and IMR-1E1 (○) was determined by DNS assay.

IMR-1E1 made 4 times more chitinase than the wild type in Reese medium with yeast extract.

The chitinase assays used in the screening procedures and for testing maximum chitinase production primarily measured endochitinase activity. Therefore, we measured CH_1 and chitobiase production by IMR-1E1 compared to the wild type. IMR-1E1 was found to produce increased levels of all activities of the chitinolytic enzyme system.

The proportional increase in all three activities suggests that IMR-1E1 contains (1) a regulatory mutation affecting coordinately controlled chitinase genes, or (2) a tandem duplication of the chitinase genes. We find that IMR-1E1 has a high reversion rate, which is characteristic of tandem gene duplications, and presently we favor this hypothesis.

In conclusion, IMR-1E1 is a valuable strain for chitinase production. The nature of the IMR-1E1 mutation is not known, but its overproduction of several components of the chitinolytic enzyme system suggests several interesting possibilities.

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Bioconversion of Chitin Wastes

UC Davis
R/F-34
1978-79

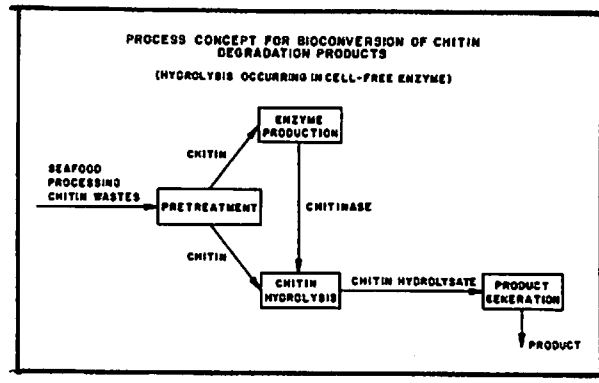
Paul A. Carroad

Processors of shellfish have faced a problem with disposal of waste. Environmental restrictions are forcing curtailment of the inland or offshore dumping of shellfish wastes, and energy costs have made hauling the wastes to sea (for dumping) unfavorable. The waste is difficult to treat because of its composition of chitin, adventitious protein, and calcium carbonate. Although others have studied converting shellfish waste--principally chitin, which is the most difficult component to treat--into certain products, commercialization of such processes has been hindered by their requiring large-scale centralization of raw material and sophisticated marketing systems. Significant markets have not developed for the proposed products, such as chitosan.

In contrast, this project focuses upon an individual large processor, or upon a locality that has several processors in proximity, and concerns design of or process for the enzymatic and microbial bioconversion of shellfish (i.e., shrimp shell) chitin to single-cell protein (SCP). This could be marketed for animal feed or as an ingredient in an aquaculture feed formulation. The goals of the project have been to establish the experimental data base needed to design the bioconversion process. The process as envisioned is shown in figure 1.

In the first step the chitin waste receives some pretreatment. At a minimum this would involve drying, size reduction, and chemical purification. A small fraction, perhaps one-tenth, of the waste is diverted to an enzyme production step. Chitin waste is used to induce a selected microorganism to secrete into solution an extracellular chitinase system in submerged culture. The enzyme is harvested by filtration and, in a third step, is combined with the bulk of the chitin waste for hydrolysis. The chitin is enzymatically hydrolyzed, principally to the monomer N-acetylglucosamine and its dimer. The hydrolysate is filtered free of undigested solids. In a fourth step it is fed to a product generation stage where, for example, it is fermented in submerged culture to single-cell protein by an appropriate microorganism. Product purification may follow as necessary.

Information has been developed on each process step to achieve an overall preliminary design.



Experimental Results

Pretreatment. The parameters investigated for protein extractions from the chitin waste were the pH of the extraction medium, the size of the shrimp shell particle, and the time of protein extraction. We selected a temperature of 30°C to avoid excessive energy expense for heating and the high cost of materials able to withstand acid and alkaline conditions at high temperatures. We studied demineralization with acid by varying similar parameters, as for protein removal, to maximize hydrolysis of chitin. Experiments were conducted in laboratory-scale reaction vessels of standard geometry to permit scale-up. Recommended conditions for protein extraction were found to be pH 11.5 to 12.0, particle size of +60 mesh, and a time of 60 minutes. Demineralization can be accomplished in six hours, in 7% hydrochloric acid with 60-mesh particles.

Selection of microorganism. Three hundred microorganisms were isolated from a variety of sources of chitin including soil, insects, and marine residues. Cultures were also obtained from other researchers and culture collections. Organisms were tested for chitinolytic activity both on agar plates containing colloidal chitin and in liquid culture using a variety of chitin substrates. The organism *Serratia marcescens* QMB1466 was judged best, based on the activity of its extracellular enzyme system and its potential for genetic improvement.

Enzyme production. Production of enzyme by *S. marcescens* QMB1466 has been studied in stirred-tank fermentors of standard geometry. We developed a mathematical model to relate the interaction between the microorganism, the solid chitin substrate, and the enzyme. A tem-

perature of 30°C and pH of 8.0 was shown suitable for enzyme production. In the current project extension, yield parameters are being quantified. Continuous culture studies indicated that depending on concentration level, N-acetylglucosamine can induce or repress enzyme production.

Hydrolysis. We have enzymatically hydrolyzed various chitin substrates. Although colloidal chitin is virtually completely hydrolyzable, chitin that has undergone less pretreatment is not completely hydrolyzed. Chitin conversion in the 20% range seems more practical for the waste treatment process. Optimum conditions are 30°C and pH 6.6. The temperature is chosen as a trade-off between rate of reaction (favoring high temperature) and enzyme stability (favoring lower temperatures). We found that a 5% chitin slurry was suitable.

Production of single-cell protein. Forty-two yeasts were screened for ability to assimilate the monomer of chitin, N-acetylglucosamine, which was shown to be the sole product of chitin hydrolysis. We selected the yeast *Pichia kudriavzevii*, based on its favorable amino acid profile and its ability to grow in a nutritionally simple medium at a high temperature (37°C and above), low pH (4.0 ±0.5). We studied dependencies of specific growth rate on temperature, pH, medium composition, and oxygen tension.

Design. We refined a sophisticated computer program for fermentor design and optimization. This program economically optimizes the entire fermentation system including aeration and agitation requirements and both medium and air sterilization. We will use this program in the forthcoming design and economic analysis.

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Cooperating Organizations

Canada Packers Co., Ltd., Ontario Canada.
National Science Foundation
University of California Agricultural Experiment Station

Storage Stability of the Purple-Hinge Rock Scallop, *Hinnites multirugosus*

San Diego State
R/F-59
1979-80

Ronald V. Josephson

The purple-hinge rock scallop (*Hinnites multirugosus*), a shellfish native to the Pacific Coast of North America, is being evaluated for commercial aquaculture through Sea Grant research carried out by Phleger and Leighton (project R/A-31). The results of their research on spawning, larval culture, growth in bay and ocean environments, and culture technology for all stages of life history are encouraging (Phleger and Leighton 1978). However, knowledge concerning the storage stability of fresh and frozen rock scallops is lacking and needed in order to know shelf-life limitations that could affect handling, storage, distribution, acceptance, and marketability of the scallop.

A review of published information on sea, bay, and calico scallops revealed that differences among genera and location and date of harvest affect gross composition and the rate of deterioration (Dyer and Hiltz, 1974; Hiltz and Dyer, 1973; Power et al. 1964; and Webb et al., 1967). Compositional variations were large enough to prevent establishment of industrial standards. Reports indicated overall refrigerated shelf-life of sea, calico, and bay scallops to range from 9 to 17 days (Power et al., 1964; Waters, 1964; and Webb et al., 1967). These differences suggested the need for a separate study to determine the fresh storage stability of the genus *Hinnites*.

There is considerably less information available on the frozen storage stability of scallops. Dyer and co-workers (Dyer and Hiltz, 1974; Hiltz and Dyer, 1973; Hiltz et al., 1974; Power et al., 1964) have evaluated frozen sea scallop meats in several studies. The samples were used as the reference control to compare with fresh samples or to evaluate biochemical and sensory changes in thawing and post-thaw keeping quality of samples frozen for one time frame, such as two months. They have not studied frozen storage stability over longer periods of time. The need for this type of information, especially for *Hinnites*, seems essential to predicting its frozen storage stability over months of commercial storage and distribution.

Therefore, our overall objective was to determine the storage stability and shelf-life characteristics of the purple-hinge rock scallop under simulated commercial conditions--stored fresh at 5°C and stored frozen at -18°C. Adductor muscles of rock scallops stored fresh or frozen were evaluated for stability by monitoring changes in their sensory attributes and acceptability and chemical, biochemical, and microbial quality. It was not possible to use cultured animals because of the quantities (approximately 400) required for this study. However, use of wild animals from the bay was not expected to detract from this study because (1) rock scallops are cultured in the same environment, and (2) there is no evidence to suggest that scallops collected in the bay or ocean would differ from each other or from cage-cultured animals in basic composition and properties. In fact Naidu and Botta (1978) showed that there was no significant difference in the proximate composition and odor, flavor, and texture of cage-cultured and wild sea scallops.

Fresh Scallop Meats Stored up to Two Weeks at 5°C

Rock scallops were harvested by scuba divers from cement pier pilings in Mission Bay, San Diego, California. We analyzed samples stored for 14, 9, 6 (postrigor), 3, and 1 (prerigor) days, following shucking according to federal specifications. This timed approach made it possible to compare samples from each storage period at the same session.

Representative uncooked (raw) adductor meats (day-1 control) contained an average of 74.3% moisture, 1.5% ash, 21.8% protein, 0.5% crude fat, and 1.9% carbohydrate. Cooked scallop meats (boiled in bag for 3-4 min) were, on a percentage basis, lower in moisture and higher in protein and carbohydrate, with cook drip composed primarily of water and a small amount of protein.

A summary of different analyses of stored scallop samples is given in table 1. Drip losses increased through day 6 and then decreased through day 14 back to similar amounts lost on day 1. There were slight biochemical changes noted during the two weeks of storage. Thiobarbituric acid (TBA) values were lower as storage progressed, reflecting little oxidation of lipid. Hypoxanthine concentration fluctuated throughout storage, indicating that nucleotide degradation was variable.

Sodium dodecyl sulfate (SDS) polyacrylamide gel electrophoresis patterns showed no evi-

dence of proteolytic change in scallop myofibrilar and sarcoplasmic muscle proteins over the two weeks of storage (patterns not shown). Total bacterial numbers increased with time, yet only the samples stored 14 days indicated questionable quality, with a resazurin reduction time of less than three hours. (Webb et al., 1972). Ammonia concentration was constantly low throughout the storage period.

Sensory evaluation of raw scallops (table 1) suggested slight, but progressive, deterioration in aroma during the second week of storage. However, sensory panels found no statistically significant change in sensory characteristics (appearance, aroma, taste, and texture) or acceptability between cooked samples from the two-week fresh storage period. Therefore, changes affecting reduced quality in aroma of raw scallops were apparently not detectible in cooked scallops.

Frozen Scallop Meats Stored up to Five Months at -18°C

Rock scallops were harvested by scuba divers from cement pier pilings at two locations: (1) Mission Bay, San Diego, California (for scallops frozen stored for months 5,4, and 3 following shucking); and (2) Nimitz Marine Facility in San Diego Bay (for scallops frozen stored 1.5 months and fresh-stored 1 day following shucking). The change in location of harvesting to San Diego Bay was necessitated by the widespread sewage contamination of Mission Bay (late February-June 1980) resulting from damage of sewage piping from heavy rains in February 1980. The timed approach used in this study meant that all frozen stored samples were compared to the fresh day-1 catch and analyzed at the same time (May 1980).

Scallops were shucked according to federal specifications, quick frozen, and held at -18°C for the four time periods by a commercial fish processor. Frozen scallops were thawed slowly at 5°C overnight (Dyer and Holtz, 1974), because slow thawing is representative of methods used in commercial handling of scallops. Samples were tested on the day they were thawed and were compared to the fresh day-1 control scallops.

Representative results of analyses are presented in table 2. Thaw drip losses were low and similar over the five months of storage. Cooked drip losses were highest in scallops frozen 1.5 months, but highly variable over the five-month period. Cooked drip composition was primarily moisture (range 87.1 - 90.4%) and

Table 1
Summary of Results of Adductor Muscle Analyses at Various Stages of Cold (5°C) Storage

Days Storage (5°C)	Flesh pH	Bacterial Counth (per gm)	Resazurin Reduction Time (hr)	Ammonia Concentration (M)	Hypoxanthine Content (mg/100 g)	Thiobarbituric Acid (TBA) Values (O.D.)[a]	Raw Odor Evaluation[b]	Cooked Samples: Different from Control (Day 1)[c]	Cooked Samples: Hedonic Mean[d,e]	Drip Loss (%)
1 (Control)[f]	6.46	108×10^1	4 - 6.5	6×10^{-6}	14	.337	Scallop-sweet - M Fishy - Sl Neutral (little odor) - M	NS	3.5	8
3	6.42	16×10^1	4 - 6.5	1.5×10^{-5}	18	.168	Scallop-sweet - M Fishy - Sl Neutral (little odor) - M	NS	3.9	12
6	6.68	7×10^1	4 - 6.5	3×10^{-5}	10	.201	Scallop-sweet - Sl Neutral (little odor) - M	NS	3.4	14
9	6.48	5×10^2	4 - 6.5	3×10^{-5}	12	.181	Scallop-sweet - Sl Neutral (little odor) - M Stale/Musty - M	NS	3.9	10
14	6.45	52×10^3	2.5	3×10^{-5}	16	.174	Fishy - M to P Stale/Musty -M Ammoniaical - Sl	NS	3.5	8

[a]O.D. = optical density measured spectrophotmetrically at 532 mm
[b]Observations of three trained expert panelists: Sl = slight, M = moderate, P = pronounced
[c]Statistical significance of multiple sample difference sensory testing by 20 trained panelists: NS = no significant difference ($p>0.05$) from control (Day 1) in appearance, aroma, taste, or texture
[d]Hedonic scale identification: 1 = disliked extremely, 2 = dislike moderately, 3 = neither like nor dislike, 4 = like moderately, 5 = like extremely
[e]Differences among mean values for various storage periods were not statistically significant ($p>0.05$)
[f]Proximate composition of raw (and cooked) control (Day 1) samples: moisture 74.4 (71.0), protein 21.8 (24.8), fat 0.4 (0.4), ash 1.5 (1.5), CHO 1.9 (2.3)

Table 2
Summary of Results of Adductor Muscle Analysis at Various Stages of Frozen (-18°C) Storage

Months Storage (-18°C)	Flesh pH	Bacterial Counts (per gm)	Ammonia Concentration (M)	TBA Values (O.D.)[a]	Thaw Drip (%)	Cooked Samples: Raw Odor Evaluation[b]	Cooked Samples: Different from Control (Day 1)[c]	Cooked Samples: Hedonic Mean[d,e]	Cooked Samples: Drip Loss (%)
Fresh Day 1 (5°C) Control	6.35	84×10^1	1×10^{-4}	.685	2.3	Scallop-sweet -Sl Fishy - Sl Neutral (little odor) - M	NS	3.0	6
1.5	6.31	29×10^2	1×10^{-4}	.474	2.4	Scallop-sweet - M Fishy - Sl Neutral (little odor)-Sl to M	NS	3.1	13
3	6.35	59×10^1	9×10^{-5}	.250	1.3	Scallop-sweet -Sl Fishy - Sl to M Neutral (little odor)-Sl to M	NS	2.6	4.5
4	6.39	35×10^2	9×10^{-5}	.265	1.4	Scallop-sweet -Sl Stale/Musty - Sl Fishy - M to P	NS	3.5	4.8
5	6.30	39×10^1	1×10^{-4}	.365	2.2	Scallop-sweet -Sl Neutral (little odor) - Sl Fishy - M	NS	3.7	8.8

[a]O.D. = optical density measured spectrophotometrically at 532 mm
[b]Observations of three trained expert panelists: Sl = slight, M = moderate, P = pronounced
[c]Statistical significance of multiple sample difference sensory testing by 19 trained panelists: NS = no significant difference ($p > 0.05$) from control (Day 1) in appearance, aroma, taste, or texture
[d]Hedonic scale identification: 1 = disliked extremely, 2 = dislike moderately, 3 = neither like nor dislike, 4 = like moderately, 5 = like extremely
[e]Differences among mean values for various storage periods were not statistically significant (>0.05)

protein (range 5.9 - 7.6%). TBA values were lower in frozen scallops than in fresh day-1 control scallops, indicating minimal lipid oxidation during frozen storage. Slight nucleotide degradation (i.e., hypoxanthine content) took place during storage. There were no apparent proteolytic (i.e., electrophoretic patterns) changes in myofibrillar or sarcoplasmic proteins (patterns not shown). Bacterial counts and ammonia concentration were low in the fresh control and in scallops stored over the five-month period.

Sensory evaluation of raw scallop aroma indicated a slight increase in fishy odor at 4 and 5 months of storage. However, as in the fresh storage study, no significant differences were found between sensory attributes or acceptability of cooked day-1 control scallops and cooked scallops from various frozen storage times.

Conclusions

Our findings indicate that the purple-hinge rock scallop has excellent fresh and frozen storage stability and shelf-life characteristics. Acceptability is comparable to that of presently available commercial scallops. This apparent suitability of rock scallops for commercial handling and storage should foster industry interest in the aquaculture and marketing of this scallop.

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Cooperating Organizations

California Department of Fish and Game
California Refrigerated Services, Inc., San Diego.
Scripps Institution of Oceanography

Analysis of Coordination among Federal, Regional, and State Policies for Managing Marine Fisheries

UC Santa Barbara
R/F-51
1978-80

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

The goal of this project has been to assess the usefulness of regional institutions for providing the coordinated management required to conserve and maintain U.S. fisheries as prescribed by the Fishery Conservation and Management Act (FCMA), and to pinpoint and evaluate the most serious obstacles for management of marine fisheries by multiple national agencies, regional fishery management councils, and state and local agencies and interests.

We have monitored the progress of the Pacific Fisheries Management Council (PFMC) in developing a management plan for the Pacific troll salmon fishery and have attended all pertinent meetings, culminating in the August 1980 meeting, in which the effort to develop a comprehensive plan was abandoned in favor of "framework" planning.

We have completed interviews with the public officials and private interests most directly involved in, or affected by the planning process, including members of the PFMC, its Scientific and Statistical Committee, Salmon Advisory Panel, and Salmon Management Work Team.

We have prepared an annotated outline of a book-length analysis entitled "Policy Implementation in a Federal System: Establishing a Regional Framework for Fisheries Management." We have completed drafts of two chapters, which are currently being revised.

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Cooperating Organizations

Departments of Fisheries and Fish and Game in the states of Alaska, California, Oregon, and Washington
House Merchant Marine and Fisheries Committee (staff)
National Marine Fisheries Service, national and regional offices
North Pacific Fishery Management Council
Pacific Fisheries Management Council
Pacific Marine Fisheries Commission
Treaty Tribe Indian Organizations
U.S. Coast Guard
U.S. Fish and Wildlife Service

Economics of Fisheries and Aquaculture Development

UC Davis/Bodega Marine Laboratory
R/F-52
1978-80

Warren E. Johnston, Cadet Hand, Louis W. Botsford, and Daniel E. Wickham

Our research on the Dungeness crab fishery is aimed at determining the cause of cycles in the northern California Dungeness crab catch record, and formulating optimal management policy. We have investigated three potential causes of cycles in crab catch. These are that catch is (1) merely following cyclic fluctuations in an environmental variable (e.g. upwelling), (2) a lagged response of effort to past catch, and (3) an inter-age, density-dependent mortality mechanism (e.g. cannibalism). These possible causes are shown schematically in figure 1.

Categories of Possible Causes of Cycles in Abundance

Environmental Variables	Predator-Prey Type Cycles	Inter-age Density-dependent Mechanism	
Upwelling	Catch-Effort	Predator worm	Cannibalism
Not cyclic but does affect abundance	The escapement-price mechanism would cause cycles of period two	Does not vary in a way that would cause cycles	Field and lab studies in progress

Figure 1. Possible causes of cycles in the northern California Dungeness crab catch.

Regarding the first possibility, we showed in 1975 that a proposed mechanism (Peterson, 1973) by which catch followed upwelling was not a likely cause of the cyclic fluctuations. Using techniques of time series analysis, we showed that although catch was correlated with upwelling in previous years, upwelling itself was not cyclic and therefore was not the cause of cyclic fluctuations (Botsford and Wickham, 1975). We have recently recomputed these statistical relationships, using an additional five years of data, with the same results. We have begun investigating the effect of related oceanographic variables such as sea surface temperature and transport. We are examining large-scale oceanographic conditions in the Pacific Basin that affect the coastal zone.

Regarding the second possibility, we have looked for a statistical relationship between effort and catch or abundance in previous years. Similar relationships have been shown to cause cyclic behavior in other fisheries (cf. Wilen, 1976; Bell et al., 1977). The major findings in this investigation are that escapement each year depends on market price, and that price depends on past values of catch (Botsford et al., in prep.). A model of this kind of mechanism was constructed to analyze stability characteristics. The analysis showed that cycles produced by this mechanism would probably be of period two years (a new, unexpected result), and would be a condition on the rate of change of escapement with past catch. Comparison of these results to the fishery showed that this mechanism is not the cause of observed nine-year cycles but may cause minor fluctuations. Further investigation of this phenomenon is planned as the responses from fisherman and processors are more clearly defined. A second result of the catch-effort study is that catch is a fairly good index of available, legal abundance. This is a result of the fact that escapement rather than effort is price dependent.

Regarding the third possibility, we have shown that mechanisms by which older animals cause mortality in the young can indeed cause cycles, and that size-selective fishing can actually make a population less stable (Botsford and Wickham, 1978; 1979). The conditions under which this mechanism causes unstable behavior depend on the rate of change of density-dependent mortality and on how much older animals of each age and sex affect this density-dependent mortality in the young. We have examined two different possible manifestations of this type of mechanism: cannibalism and an egg-predator worm. Analysis showed that the worm did not fit the conditions necessary to cause the cycles.

We are pursuing additional modeling, field, and laboratory work on cannibalism. The field study consists of sampling relative settlement and abundance through the summer, as well as examining crab gut contents to determine summer levels of cannibalism. Results of samples from Humboldt Bay in the first year showed relatively high levels of cannibalism in June (17 crabs found in guts of 48 crabs) and a lower level in July. Limited sampling outside the bay showed higher abundance. In the second year there was a very low number of newly settled and one-year-old crabs in the bay. Sampling outside the bay was again limited by logistic problems, but increased sampling outside the bay has a high priority for future years.

Laboratory studies on cannibalism have shown that gut evacuation times are less than 24 hrs. This implies that observed cannibalism is a minimum estimate of daily rate.

Modeling work regarding cannibalism involves further examination of the assumption made in the original crab model. This is based on a review of the literature and examination of size frequencies provided by the California Department of Fish and Game. Results thus far show that actual growth rates may be different from those used earlier, and that the extremely high landings during the 1975-76 to 77-78 seasons may have resulted from a single (phenomenal) year class.

The results of new data and literature reviews have been combined into a more realistic simulation model of the Dungeness crab population. This model includes more realistic growth rates, size distributions, populations both inside and outside of bays, and other improvements. This model will enable us to further test some of the proposed theories of crab abundance, as well as to examine the effects of different management policies.

For the second part of our crab study, determination of optimal policy, we have developed new results for general age or size-specific fishery models with both density-dependent growth and recruitment. Our results indicate that pulse-fishing rather than fixed, constant policy is optimal to maximize present value of the fishery. The specific implications of these results for the crab fishery will be determined in the coming year. This task has been planned for the third year to allow as much time as possible to investigate inter-age interactions in the population. The relative effect of older animals at each age and sex is a critical factor in determining optimal policy. We also plan to apply the general results of the optimal harvest analysis to pond harvest problems in aquaculture.

Studies of the crab egg predator *C. errans* have shown that this worm does not appear to cause the cycles in abundance. Worm abundance and the resulting egg mortality do not change rapidly enough with crab abundance. This conclusion may change as we observe the declining phase of the cycle. However, the worm has increased to high levels in Eureka in the past six years and is currently at relatively high levels in Oregon and Washington. The increased number of worms per crab egg may be due to the recent increase in crab abundance. If worm-induced egg mortality actually does affect crab population size, this worm could cause reduced crab populations in these areas.

During the past year we have updated economic parameters in the lobster model and revised our cost projections. Culture costs have increased by approximately 37% over the period from 1976 to 1980 (Johnston and Botsford, 1980). We have also continued work on the monograph *The Bioeconomics of Aquaculture, A Systems Approach.* In addition to applying new general optimal harvest policy results to the crab fishery, we are applying them to pond aquaculture.

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Crowded marina in Eureka harbor. (Photo by Jens Sorensen)

An Economic Analysis of the California Abalone Fishery and the Experimental Enhancement Program

UC Santa Barbara
R/F-53
1978-80

Robert T. Deacon and Perry Shapiro

Between about 1950 and the latter portion of the 1970s, a variety of dramatic changes were observed in the California abalone fishery. The size of the commercial catch, which had been relatively constant at four to five million lbs per year (live weight) until about 1967, declined during the following decade to about one-third of its former level. Between 1950 and the late 1960s, the number of licensed commercial divers increased by a factor of about three, and then remained relatively constant during the ensuing decade. Exvessel prices, adjusted for inflation, rose gradually between 1950 and about 1967 (the total price increase during this period was about 70%, when measured in "constant dollars"). During the next ten years, real U.S. prices roughly tripled. Any successful analysis of the California abalone fishery must be able to explain these dramatic events. Consequently, this progress report is structured around attempts to understand these phenomena.

The usual reason attributed to declining catches in the face of increased fishing effort is overfishing. Overfishing, in a physical sense, would be present if the amount of fishing effort (commercial fishing pressure) directed at the fishery exceeded the level required to obtain the maximum sustainable catch. Increases in effort beyond that level may, by impairing the regenerative capacity of the population, reduce sustainable catches. Although the observed trends in catch and effort are consistent with this explanation, it is difficult to see how this explanation could be accurately applied to the California abalone fishery. The difficulty stems partly from the fact that the fishery is size- and age-selective. That is, size (and, implicitly, age) limits apply to the commercial catch, and size distribution surveys indicate that these limits are largely observed by the industry. If recruitment were constant (i.e., independent of the level of the commercial harvest), then maximum catch would be limited by the mass of cohorts reaching legal size each year. If environmental factors did not vary, this limit would be constant, independent of the level of commercial fishing. Thus, for increased fishing pressure to be responsible for declining catch levels, it must be the case that commercial fishing impairs recruitment.

However, analysis of estimates for natural mortality rates, growth of individual members of the population, and fecundity indicates that this is unlikely. In particular, existing information on fecundity (age at sexual maturity and fecundity as related to body weight), growth rates in individual abalone, and estimated natural mortality rates indicates that, in the absence of commercial fishing, only a relatively small fraction of a cohort's potential reproductive capacity would be available during years when it is above current legal size limits. For pink and green abalone, estimates of this fraction are typically below 10%. Even if relatively generous estimates of survival rates are used (in particular, if survival rates are assumed to increase with age) the fraction may rise to 20-22%. But, in any case, it seems most unlikely that commercial fishing pressure, with existing size limits, could reduce recruitment enough to account for more than a small portion of the actual declines in catches observed since the mid 1960s.

These findings led us to attempt to corroborate the mortality rates used in these calculations with independent estimates. Estimates were derived from existing size distribution surveys; the estimates obtained did not differ substantially from those reported in other sources. We are also using size distribution data in an attempt to estimate rates of mortality caused by commercial fishing. Related to this is our attempt to model the transition in catch levels and in age distributions that occurs when size limits are changed. By studying such transitions and comparing them to actual changes in catch levels when size limits are changed, we hope to obtain independent estimates of natural mortality and fishing mortality rates.

(It may seem surprising that an economic analysis of the fishery and of the experimental enhancement program is devoting so much attention to biological factors. However, existing evidence clearly indicates that natural mortality rates and the amount of time required for the varieties of commercial abalone to grow to legal size are factors of central importance to the economic attractiveness of the enhancement program.)

Though we have not drawn final conclusions

regarding whether or not overfishing is responsible for declines in catch levels, it does appear prudent at this point to search for alternative explanations. The most obvious alternative explanation is the increase in range and numbers of sea otters inhabiting the California coast south of Point Lobos. A problem with quantifying this effect lies in lack of hard time series data on otter populations and locations. We may be able to partially compensate for this by examining catch records from areas that have not yet been subject to significant otter predation. Other alternative explanations are also being pursued.

Regarding the dramatic price changes experienced in the market for abalone, the most obvious explanation would appear to be the historic decline in catch levels experienced since the latter 1960s. However, a closer analysis of the problem indicates that this explanation is faulty. In particular, data on imports of canned and frozen abalone (primarily from Mexico) indicate that declines in domestic supplies were largely made up by increases in imported products. Moreover, the close correlation (above .99) between prices of domestic and foreign products indicates that the two are highly substitutable. Thus, the price observed in the domestic market will be partially influenced by supply conditions for imported abalone. To determine the degree of influence, it was necessary to estimate the supply elasticity of abalone available for import to the U.S. To accomplish this, it was necessary to estimate supply and demand functions for abalone traded in international markets. Using simultaneous equations techniques, and allowing for an autocorrelated error structure, we estimated these functions. With these estimates, it was possible to derive the price elasticity of supply for imports to the U.S. Our point estimates of this elasticity are all relatively high (typically between 10.0 and 20.0). This indicates that domestic price levels are virtually completely determined by prices at which imported products are available.

Given these findings, one may well ask why abalone prices have risen so rapidly in domestic markets since the late 1960s. As the preceding discussion indicates, the answer may be found by investigating price trends in international markets. Measured in terms of the currency of the major consuming nation (i.e. Japanese yen), inflation-adjusted abalone prices have been remarkably stable since 1950. Between 1950 and 1967, there was only a slight price increase on international markets; since 1967, prices have remained roughly constant. This relative stability reflects a similar degree of stability in foreign supply-demand conditions. Thus, the increase in U.S. prices can be primarily attributed to the rapid decline in the value of the U.S. dollar vis à vis currencies of other consuming nations in international currency markets.

These findings are also of direct importance to the economic viability of a commercial enhancement program, since they indicate that increases in domestic supplies would largely replace imports, and would not tend to significantly depress domestic prices (unless domestic supply rose to the point where it completely replaced imported products).

We have also begun analysis of data on the regional and temporal distribution of commercial fishing activity (e.g., as measured by numbers of licensed divers, boats, gear units, etc.). At present, we are attempting to reconcile inconsistencies in data available from two different sources (National Marine Fisheries Service and California Department of Fish and Game). When these apparent inconsistencies are resolved, we will proceed to empirically analyze the effect of changes in commercial fishing pressure upon catch levels.

Cooperating Organizations
California Department of Fish and Game, Long Beach and Morro Bay
National Marine Fisheries Service, Long Beach
Seafood Specialties, Inc. Santa Barbara

Economics of Swordfish Vessel Participation and Catch

San Diego State
R/F-54
1978-79

Suzanne Holt

Under extended jurisdiction, a preliminary fishery management plan has been written for Pacific billfishes and sharks, and may substantially affect the California swordfish fishery. It is important to understand the factors that influence swordfish vessel participation in different fisheries. The major objectives of this project were (1) to investigate the determinants of, and variations in swordfish vessel participation rates in different fisheries, (2) to develop improved cross-section and time-series swordfish vessel production functions, (3) to evaluate the effectiveness of scouter aircraft use in swordfish fishing, and (4) to develop catch per-unit-effort measures for the 1974-78 swordfish seasons.

The attempt to explain participation rates met with limited success. The typical commercial swordfish vessel fishes more for recreation than for income. For example, in 1978 the average vessel fished 17 days in a season of some 100 fishable days. Seventy-five percent of all swordfish were caught by only 25% of all vessels. In addition, swordfish vessels participated in such distinct fisheries besides swordfish (albacore tuna, salmon, rock cod, shark, crab, squid, sablefish, etc.) that no common profile of other fisheries could be readily drawn for the typical vessel. The more successful vessels, however, tended to be tuna-swordfish or groundfish-swordfish vessels.

The explanation of participation rates drew on a mail survey and a regression model. The mail survey consisted of a random sample of 100 of the 800 vessels active in 1978, stratified by catch rates and years of experience. With a response rate of 40%, the survey provided data on fishing costs, tastes, and time spent in other income-earning activities, as well as vessel participation rates (days fished) and landings in all fisheries for 1978. These data were then combined with data on years of experience, availability of swordfish and other species, and ex-vessel prices for all relevant species. A regression model was developed to explain swordfish participation rates by vessels as a function of species availability, ex-vessel prices, fishing costs, years of experience, tastes, and other sources of income.

The regression results were statistically disappointing. First, the survey process made it prohibitively expensive to collect data on these variables for any other than the most recent fishing season. Unfortunately, the data were not available from any other source. The 1978 season followed on the most successful fishing season (fleet landings of three million pounds in 1977), and some 800 vessels turned out to catch a dramatically reduced number of swordfish. Second, noncommercial variables (tastes, other sources of income), along with experience and availability, were more statistically significant in explaining vessel participation rates in swordfish than were commercial variables (relative ex-vessel prices and relative fishing costs). These results are to be expected given the relatively strong sports orientation of the typical vessel and given that the data were available only for a single year. Finally, the reliability of the regression results for predicting future participation rates is limited by the inability of the model to predict the behavior of potential entrants to the fishery. The expansion of the fleet from some 500 vessels in 1977 to 800 in 1978 speaks dramatically to the significance of entrants in explaining fleet participation rates.

The participation rate analysis would be greatly improved by a longitudinal study of these factors, should such information prove important to the Billfish Fishery Management Plan.

The objective of improving cross-section and time-series vessel production functions met with great success. Vessel landings were explained as a function of days of fishing, days of spotter aircraft use, vessel characteristics (length, horsepower), environmental conditions (water temperature and color), and a residual variable indicating fishing skill. The skill variable proved most significant, accounting for between 45 and 60% of landings variation. It was to be expected that skill would vary substantially for a fleet that is not primarily income-oriented. The regression results provide a more complete explanation of the fishing power of different vessels as well as the fishing power of spotter aircraft.

The production function format did not prove necessary to evaluate the effectiveness of scouter aircraft (aircraft scouting for swordfish but not assisting in the catch). Although the swordfish logbooks provided for the use of scouter aircraft, less than 1% of the vessels ever

reported using scouter aircraft. California Fish and Game regulations prohibited any aircraft use beyond reconnaissance after the 1975 season, and such use apparently was totally ineffective in increasing vessel landings.

Finally, the catch-per-unit-effort measure for 1974-78 fleets was generated, using indexes of relative fishing power of aircraft-assisted vs. unassisted vessels derived from the production function analysis. These data serve as indexes of fish availability and will be valuable additions to the Billfish Fishery Management Plan.

The various tasks of this project were designed to fill important gaps in understanding the behavior of the swordfish fleet and its responsiveness to fishing and economic conditions. The participation rate model is an important first step toward a more thorough understanding of the factors affecting fishing behavior across species. The production function model permits a complete analysis of various productivity factors in fishing and the calculation of relative fishing power. The combination of participation rates and fishing power can then be used to model the domestic fleet fishing capacity. Reliable capacity estimates have been a major problem in most fishery management plans, and our research has developed an important methodology for these estimates.

Cooperating Organizations
Billfish Fishery Management Plan Development Team
California Department of Fish and Game
National Marine Fisheries Service

New Marine Products

Pharmacological Evaluation Program

Robert S. Jacobs

During the course of this grant we have examined several hundred marine-derived natural products and evaluated their pharmacological properties. In this report we present those marine natural products of greatest interest to us at this time.

Stypoldione

Stypoldione, isolated from the brown alga, *S. zonal*, was shown toxic to reef-dwelling fish. This compound is the most potent inhibitor of cell division in sea urchin eggs we have identified in our studies. The dihydroxy analog (stypotriol) was reported more toxic to fish than stypoldione, yet this close derivative proved inactive against cell division. This prompted us to conduct further studies of stypoldione with the view that blocking cell division may involve a mechanism separate from fish toxicity.

Stypoldione was administered to groups of mice at doses up to 100 mg/kg. No deaths were observed after 24 hours following a single dose. In experiments where administration was repeated daily (25, 50, and 100 mg/kg) in mice infected with Ehrlich ascites tumor cells over a 12-day period, the observations in table 1 were made.

Table 1

Treatment	*n*	*Weight gain (%)*	*Mortality*
Normal mice	10	21.9	0/10
Ascites tumor mice	10	53.3	1/10, 10th day (1)
+25 mg/kg stypoldione/day	10	38.2	1/10, 11th day (1)
+50 mg/kg stypoldione/day	10	13.2	1/10, 3rd day (1)
+100 mg/kg stypoldione/day	10	8.5	4/10, 3rd day (1) 9th day (1) 12th day (2)

In rapidly growing ascites tumor cells *in vivo*, treatment with stypoldione at 50 mg/kg daily (subcutaneously) prevented excessive accumulation of ascites fluid. Weight gain was similar to normal uninfected mice. Samples of ascites fluid from these mice revealed the presence of tumor cells but, compared to controls, the concentration and total numbers were reduced.

At 100 mg/kg the mice lost weight relative to normal mice, and a toxicity of greater incidence than that seen in tumor-infected animals was evident. In the surviving treated animals ascites fluid was minimal, and a relatively small number of tumor cells were present. The experiment at 100 mg/kg was repeated to verify the toxicity. In this case there was a mean weight increase of 41% in the control animals and 29% weight increase in those treated with 100 mg/kg stypoldione. Mortality was 3/10 in controls and 2/10 in the treated animals. Thus in the second experiment the beneficial effects of the stypoldione were seen, but not the mortality. In summarizing these data I have concluded that stypoldione is able to inhibit dividing Ehrlich ascites tumor cells *in vivo* as well as inhibit cell division in dividing sea urchin eggs. The toxicity observed at 100 mg/kg is not conclusive and requires further investigation.

Because there is uncertainty as to the relevance of the sea urchin egg and the Ehrlich ascites tumor cell to human cancer, investigations were undertaken with stypoldione to determine if cell division was inhibited in human cancer cells grown in tissue culture. Thus far our results indicate that stypoldione inhibits growth of human melanoma cells *in vitro* (table 2). In control cells over a 3-day reproduction cycle, the melanoma cell number increased approximately 200%. At concentrations of stypoldione from 2 ug/ml to 16 ug/ml, melanoma growth was reduced at the lowest concentration and abolished at the highest concentration. Visual observations of the growing cells revealed the following: at the highest concentration the cells did not divide following subculture and were observed to be rounded and floating in the medium. Some cells had adhered to the culture flask in a normal fashion but did not replicate. Lower concentrations of stypoldione allowed growth to occur to some degree. There was little evidence of lysed cells at any concentration.

Table 2
Effects of Stypoldione on Human Melanoma Cells *in vitro*

Group	*% Increase in cell counts from day 0*		
	Day 1	Day 2	Day 3
Control	85	175	190
2.0 ug/ml	67	173	163
4.0 ug/ml	40	156	154
8.0 ug/mi	12	102	61
16.0 ug/ml	-48	-64	-67

We conclude that this substance is worthy of further investigation into its anticancer potential. Special studies are planned to explore its

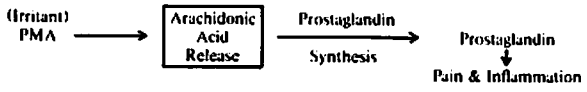
action in human cancer cell lines grown in mice. *A word of warning*: excessive optimism as to the therapeutic potential of this substance is *not* warranted at this time. Furthermore, the toxic or harmful effects of stypoldione remain to be explored.

JF-133

An anti-inflammatory agent from marine sources has been identified from our screening studies. This substance (JF-133) isolated from a sponge has proved active both as an analgesic and anti-inflammatory agent.

Phenylquinone, when injected into mice, causes pain characterized by writhing. JF-133 was found to protect mice from this writhing when administered subcutaneously at 80 and 20 mg/kg. The activity was generally weak but uniformly reproducible. The onset of action was delayed compared to aspirin and morphine: the peak effect was detected about two hours after administration.

On the basis of these preliminary results we began studies to determine if JF-133 had a profile of activity similar to the analgesic anti-inflammatory agents such as aspirin and indomethacin or whether its analgesic action was similar to morphine. For anti-inflammatory activity we elected to study the compound in the PMA-induced inflamed mouse ear. For morphine-like activity we used the electrically driven ileum as well as the Haffner technique. JF-133 was found to be topically active in the PMA test but not active in any of the assays in which morphine was active. Because of these results we presumed JF133 was primarily an anti-inflammatory agent, and we proceeded to determine if its actions were similar to or different from indomethacin (a known prostaglandin synthetase inhibitor). Indomethacin is presumed to prevent formation of prostaglandins implicated in some forms of pain and inflammation. The working hypothesis for the PMA-induced inflammation is as follows:*



Inflammation can be induced in the mouse ear by actions at one of two steps in this scheme: (1) administration of PMA to induce release of arachidonic acid and (2) direct administration of arachidonic acid.

Figure 1 is a dose-response curve showing the effectiveness of JF-133 in blocking PMA-induced inflammation. The ED_{50} is estimated to be 5 mg/ml applied topically. For comparison, the ED_{50} of indomethacin was found to be 12 mg/ml, and hydrocortisone about 0.7 mg/ml. Thus, in this study JF-133 was more potent than indomethacin and less potent than hydrocortisone. Figure 2 shows the results of studies with arachidonic acid-induced inflammation. In this case JF-133 was definitely not effective; in fact, it tended to increase inflammation. Hydrocortisone was only weakly active at the concentration employed, whereas significant activity was seen with indomethacin.

The conclusions we have drawn from our studies with JF-133 are as follows: (1) This compound is clearly a topically active anti-inflammatory agent. (2) It is effective against PMA-induced inflammation but not against arachidonic acid-induced inflammation. Therefore, based on the data available it appears that JF-133 acts by a mechanism different from indomethacin--possibly at a step early in the initiation of arachidonic acid release.

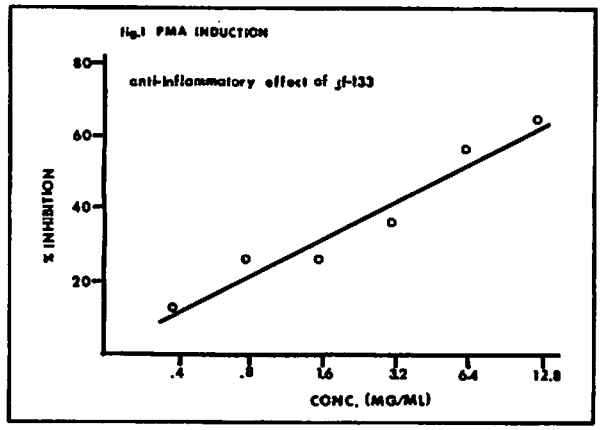


Figure 1

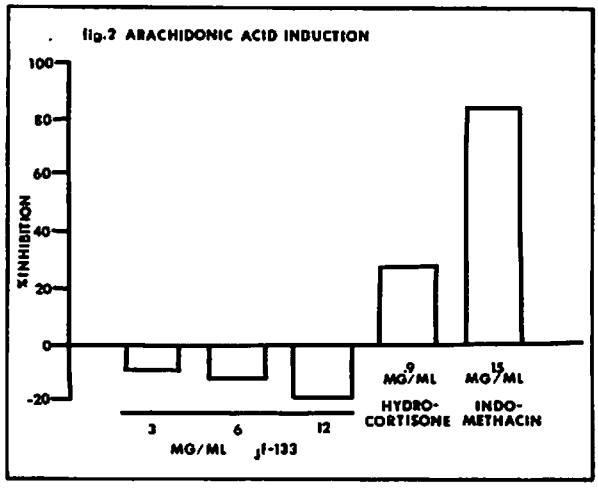


Figure 2

Lophotoxin

We have undertaken an investigation of the mechanism of action of Lophotoxin isolated

*Not all investigators concur with this model.

from the soft coral, *Lophogorgia rigida*, after it was found to produce muscle paralysis and death in mice. In the isolated rat diaphragm we found this substance to produce an irreversible paralysis during nerve stimulation but not when the muscle is stimulated directly (figure 3).

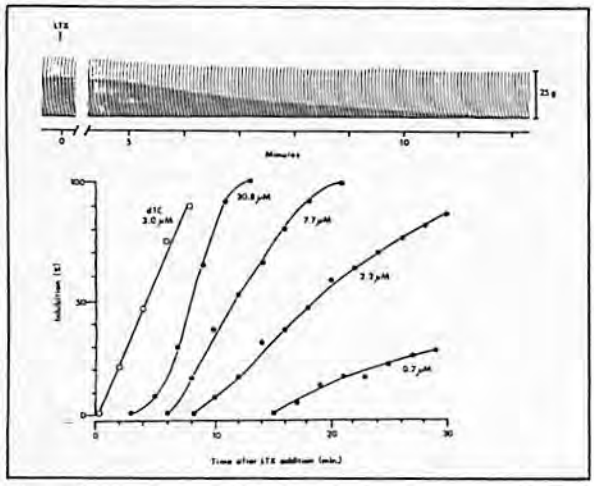


Figure 3

Another feature of this toxin is a latency of onset not seen with curare. That is, as the concentration is decreased, there is an increased delay before muscle paralysis ensues. This effect is similar to that seen with the snake venom α-bungarotoxin.

The main objective in studying Lophotoxin has been to determine whether the mechanism is unique from other toxins. To accomplish this we have studied whether Lophotoxin would compete with curare or α-bungarotoxin. Thus far our findings support the hypothesis that Lophotoxin binds to a site on the muscle end plate that is different from either of these classical agents. The study of Lophotoxin is therefore increasingly important, for it may be a probe that can be used to study neurophysiological problems.

In summary, our marine pharmacology studies have uncovered three substances of potential importance. The sea urchin assay yielded a compound that is active *in vivo* in a mouse tumor assay and *in vitro* against melanoma cells. Other tests have yielded a compound that is analgesic and anti-inflammatory, and the toxicity assay has disclosed the existence of a previously unknown neuromuscular toxin.

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Cooperating Organizations

Bristol Myers Corporation
Syntex Corporation

Marine Natural Products for Pharmacological Evaluation

D. John Faulkner

During the two-year period of this grant we have isolated and identified 65 marine natural products and have submitted these compounds for pharmaceutical evaluation by Dr. Robert Jacobs. We have also prepared over 100 crude extracts for screening. Some of the compounds submitted for screening had been found previously by other investigators, but had not been subjected to pharmacological screening. It was among these compounds that we have found the most promising new pharmaceutical agent. The compound (code #JF-133) has anti-inflammatory activity and compares well with the drug indomethacin. At the time of writing this report, the identity of the compound is being withheld. Full details of the pharmacological screening data and the interpretation of the data will be found in the final report submitted by Dr. Jacobs (R/MP-15).

This report will concentrate on the isolation and structural elucidation of new marine natural products and the synthesis of some simple derivatives. We have studied marine organisms from Belize, Palau, Canton Atoll, the Gulf of California, and La Jolla. The majority of the marine organisms studied were sponges, because of the availability of material and the high incidence of pharmacological activity recorded for crude extracts of marine sponges. We have also studied the use of certain field observations to identify marine organisms with a higher-than-average probability of containing biologically active compounds.

We have studied six sponges of the genus *Plakortis* that were identified by Dr. Klaus Rützler (Smithsonian Institution) as either *Plakortis halichondrioides* or *Plakortis* sp. We had previously obtained plakortin (**1**)* from a sample of *Plakortis halichondrioides* collected at San Blas, Panama (Higgs and Faulkner, 1978). To our surprise, we obtained two identical-looking samples of *P. halichondrioides* from Belize, one of which (77-100) contained plakortin (**1**), while the other (77-084) contained 3-epi-plakortin (**2**), and 9,10-dihydro-3-epi-plakortin (**3**) (Stierle and Faulkner, 1980). A third sponge, *Chondrosia collectrix* (77-098), produced two cyclic peroxides (**4** and **5**) that were again epimeric at C-3 (Stierle and Faulkner, 1979). A different sample of *P. halichondrioides* (77-097) did not contain any cyclic peroxides but has instead provided a series of aromatic compounds such as the δ-lactone **6**, the γ-lactone **7**, and the β-hydroxy ester **8** (Ravi, Armstrong, and Faulkner, 1979). The connection between the apparently unrelated cyclic peroxides **1-5** and the aromatic compounds **6-8** was provided when the aromatic peroxides **9** and **10** were isolated from a *Plakortis* sp. (77-044) (Stierle and Faulkner, 1980). Another sponge designated *Plakortis* sp. (77-096) was found to contain cyclic peroxides having yet another carbon skeleton. Although the cyclic peroxides were the compounds of most interest in these sponges, we also found a number of related metabolites exemplified by structures **11-18** (Higgs and Faulkner, 1978; Stierle and Faulkner, 1979; 1980). *Plakortis zygompha*, by way of contrast, contained a series of relatively simple metabolites **19-22** (Faulkner and Ravi, 1980). The cyclic peroxides did not show any useful pharmacological activity. We tested the hypothesis that they might resemble intermediates in the biosynthesis of prostaglandins and thus inhibit prostaglandin synthetase, but they do not have the expected anti-inflammatory activity.

We have examined several samples of *Agelas* species. Each of these sponges contained both lipid-soluble and water-soluble antimicrobial metabolites. The lipid-soluble compounds were usually simple derivatives of 4-bromopyrrole-2-carboxylic acid or 4,5-dibromopyrrole-2-carboxylic acid. However, the water-soluble metabolites have been identified as oroidin (**23**) and sceptrin (**24**). The structure of sceptrin (**24**), determined by x-ray crystallographic analysis is an unusual cyclobutane-containing dimer of an oroidin-like molecule. (Walker et al.). Sceptrin has antifungal activity and is being evaluated by a pharmaceutical company. A similar evaluation of variabilin (**25**) (Faulkner, 1973) is being performed.

Two antimicrobial constituents have been isolated from the sponge *Siphonodictyon coralliphagum*. We first became interested in this sponge because it burrows into coralheads and maintains a ring of dead coral polyps around the oscular opening. The antimicrobial compounds siphonodictyal-A (**26**) and siphonodictyal-B (**27**)

*For this and all succeeding boldfaced numbers, please refer to corresponding boldfaced numbers in figure 1.

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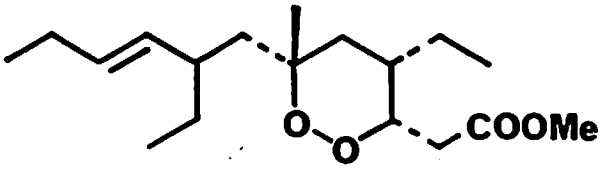

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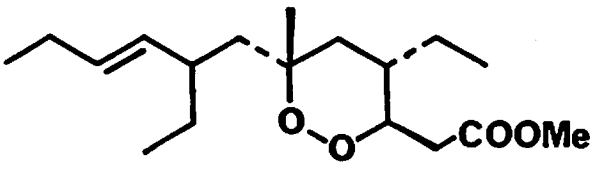

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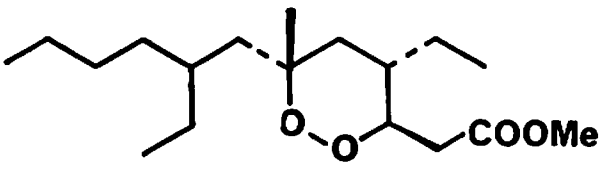

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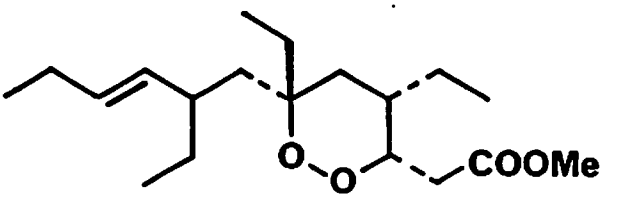

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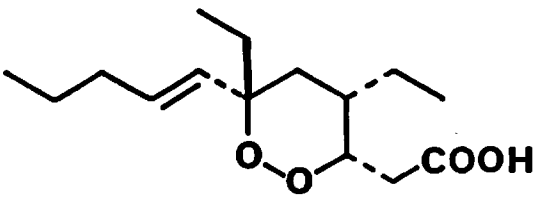

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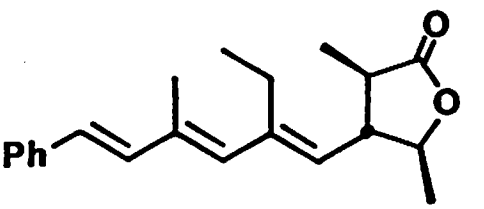

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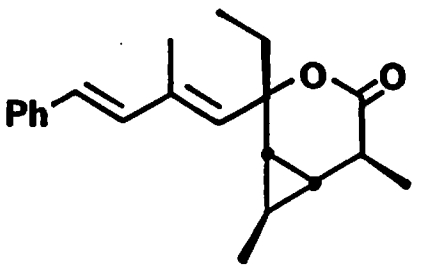

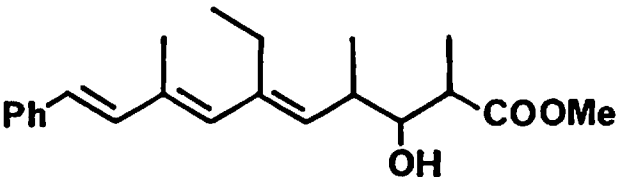

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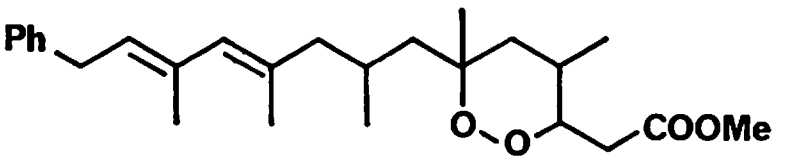

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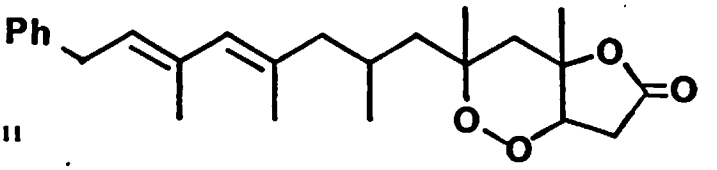

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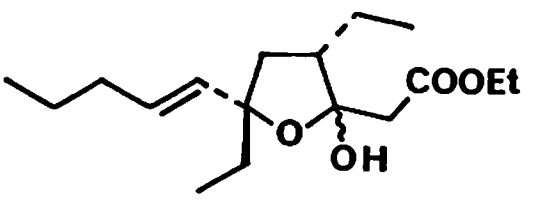

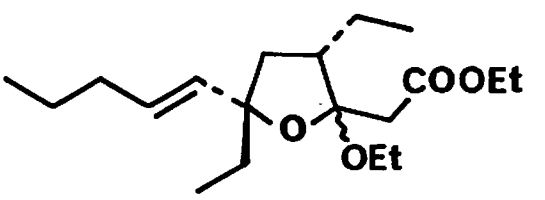

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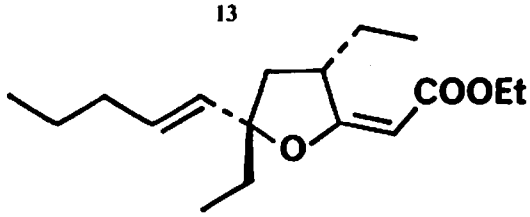

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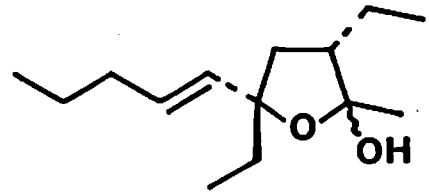

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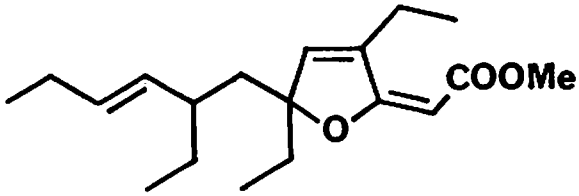

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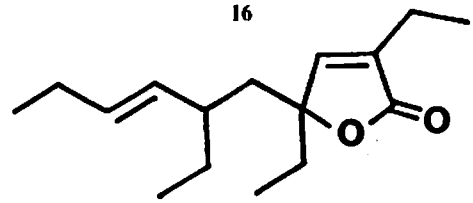

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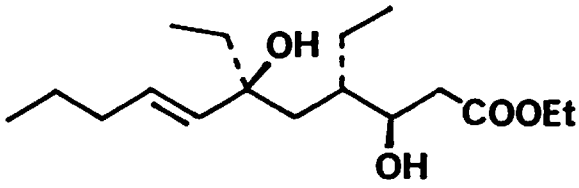

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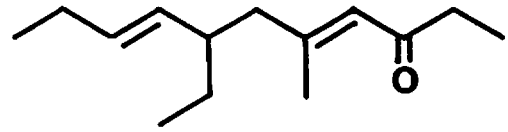

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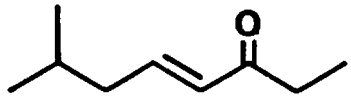

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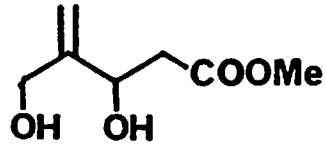

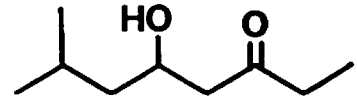

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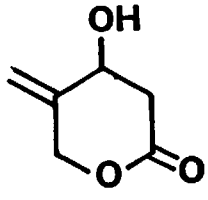

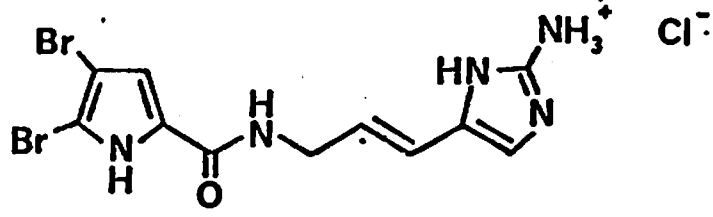

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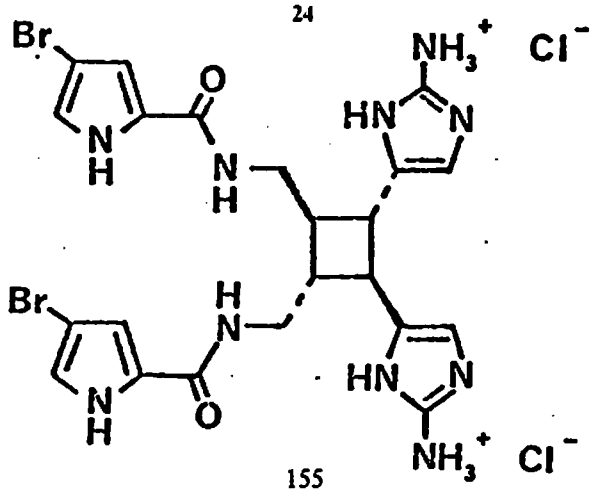

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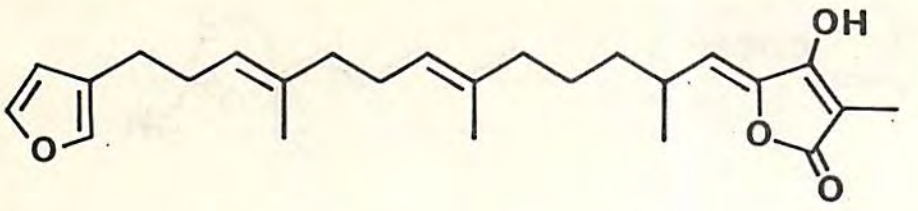

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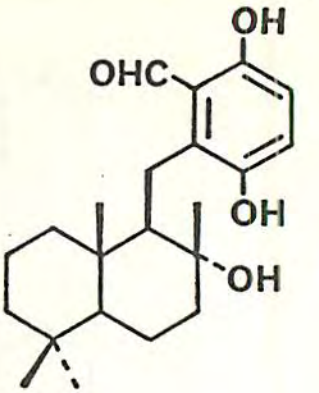

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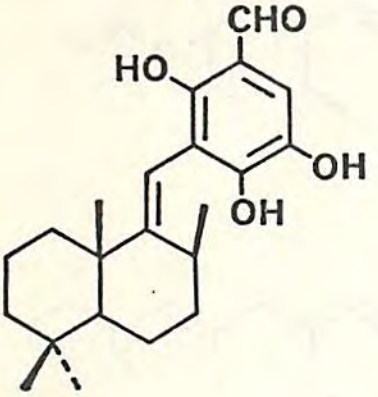

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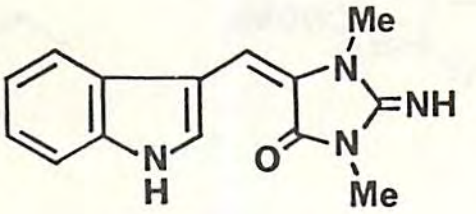

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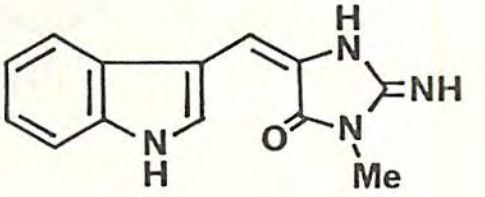

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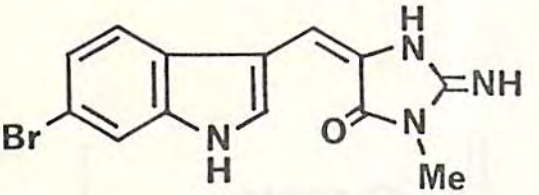

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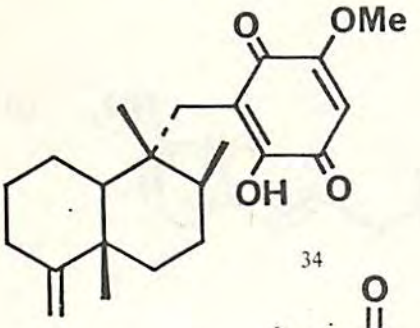

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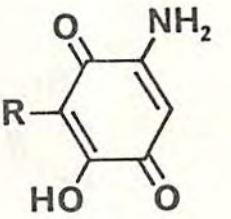

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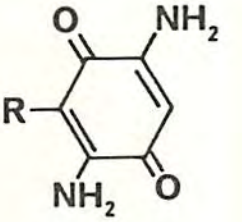
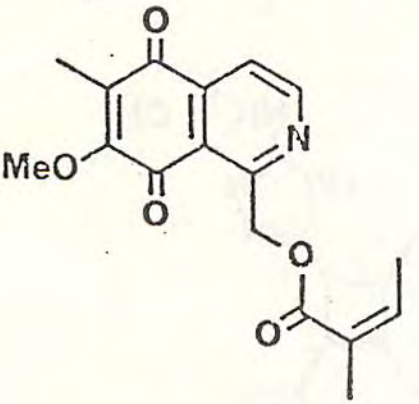


34



were identified from spectral data, and the structures were confirmed by interconversion with known compounds. Since the sponge burrows into a calcium carbonate substrate, we suspected that siphonodictyal-A and -B might be involved in calcium ion transport, but we have been unable to detect ionophoric properties for these molecules.

The sponges *Smenospongia aurea* and *Smenospongia echina* contained several novel compounds, including the antimicrobial compounds 5-bromo-N,N-dimethyltryptamine and 5,6-dibromo-N,N-dimethyltryptamine (Djura et al., 1980). The metabolites **28-30** of the sponge *Dercitus* sp. (Djura and Faulkner, 1980) were of special interest, since researchers at RRIMP had found that a derivative of aplysinopsin (**28**) had pharmacological activity. We were unable, however, to better their results.

Some results obtained by Dr. Jacobs indicated that quinones were often active in a cytotoxicity assay using fertilized sea urchin eggs. (See the report on project R/MP-15 for details.) We therefore prepared the mono-amino quinone **32** and diaminoquinone **33** from illimaquinone (**31**) that we had obtained from *Ianthella ardis*. The rationale for this modification was that aminoquinones such as mitomycin-C showed strong cytotoxicity. The aminoquinones did not have better antimicrobial activity than illimaquinone and were marginally cytotoxic in the sea urchin assay. We prepared the corresponding quinones from avarol (Minale, Riccio, and Sodano, 1974) and from 5-hydroxy-8-methoxycalamenene (Kashman, 1979). These compounds were both active in the sea urchin assay.

Our major study of quinones, those obtained from *Reniera* sp., is still in progress. We have reported the isolation and structural elucidation of renierone (**34**), the major antimicrobial constituent (McIntyre et al., 1979).

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Cooperating Organizations

Syntex Corporation

New Agricultural Chemicals from Marine Organisms

UC San Diego
R/MP-18
1978-80

William H. Fenical

The major objective of this project was to explore the metabolites of marine plants and animals for their potential use in agricultural applications.

The project was conducted with the close collaboration of several industries: Stauffer Research Laboratory, Zoecon Corporation, and FMC Corporation.

In addition to financial assistance, these collaborators contributed considerable biotesting resources. The types of assays involved included the following partial list:

Biocide: antibiotic assays against pathogenic bacteria and deleterious plant fungi

Antidotal activity: assays to indicate "protection" against wilt and other side effects from existing herbicides

Insect growth regulation: assays to detect the influence of chemicals upon normal insect growth and development

Insecticides: assays for toxicity against salt-marsh caterpillar, aphids, tobacco budworm, cabbage looper, mosquitoes, houseflies, spider mites

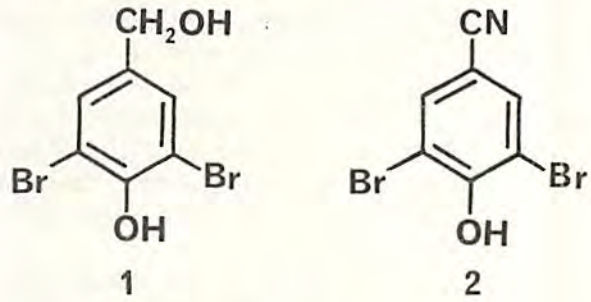
Nematocides: an assay to detect systemic control of pathogenic nematodes

Other miscellaneous assays: a few assays were conducted to assess synergistic activity, and an increase in the potency of an existing insecticide. In addition, an antijuvenile hormone assay was completed.

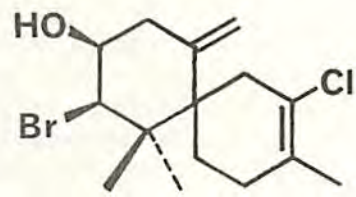
During the second year of this project the pharmacology program at Santa Barbara evolved, and we worked with Professor Jacobs to investigate the biomedical potential of all compounds isolated. It was impossible to provide each compound in sufficient quantity for both agrichemical and pharmacological testing; however, a considerable effort was made to do so.

Over the project period, 140 purified compounds were subjected to agrichemical bioassay, and 95 substances were also screened by Professor Jacobs. Stauffer Chemical Company tested 15 compounds in 1977-78, and found 9 of them to exhibit some form of activity.

Their finding that the bromo-phenol *1*, isolated from red seaweed, functioned as an herbicide antidote was particularly important. This induced Stauffer to reinvestigate bromoxynil (*2*), an older herbicide abandoned in favor of new products. They found that bromoxynil was quite active as an antidote. Thus the similarity of the natural product *1* with *2* was responsible for a unique discovery.



1 2



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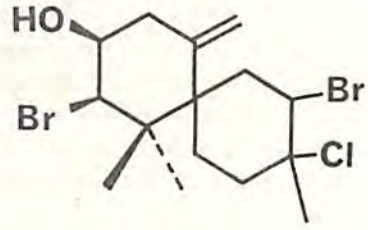
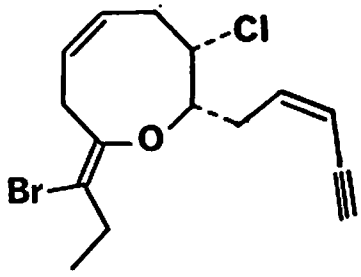


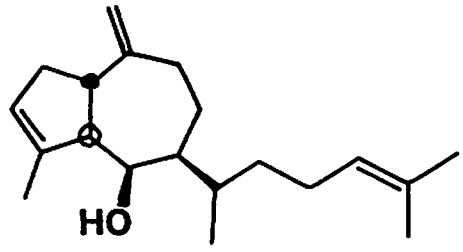
4

Also noteworthy was Stauffer's finding that the sesquiterpene *3* (elatol) was insecticidal (LD_{50} 0.05% against cabbage looper, 0.2 ppm against mosquitoes, and 0.4 μ gm/cm^2 against milkweed bug). Preliminary testing further showed that *3* acted as an antijuvenile hormone, causing premature metamorphosis (milkweed bug). The related terpene *4* showed a similar activity but at higher levels (LD_{50} 8 μgm/cm^2). Since Stauffer was not capable of further investigations of anti-JH activity, we consulted Zoecon Corporation, which specialized in hormonal insect control methodology. In 1978-79 we provided Zoecon with a massive re-collection of the elatol-producing red seaweed to produce 78 grams of pure elatol for further bioassay. After two years of biotests, the answer is not yet complete. It appears, however, that elatol is a

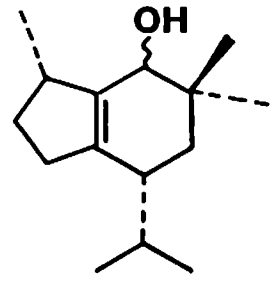
Figure 1. Other Agrichemical Testing Data



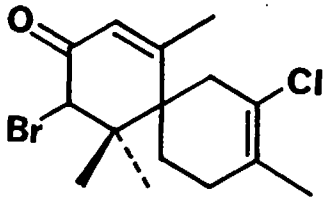
LD_{50} = 0.1 ppm black bean aphid
LD_{50} = 0.1 ppm saltmarsh caterpillar
100x increase in SEVIN activity



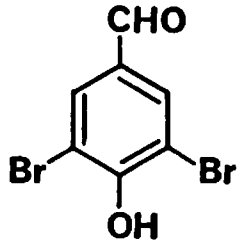
90% preplant control curlydock
25% systemic nematicide



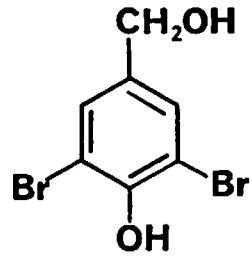
76% control fungus
(*Phytophthora infestans*)



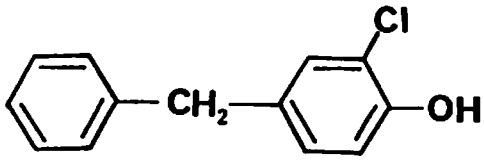
36% control spider mite



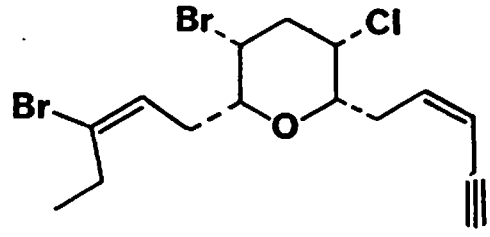
95% control mustard
antidotal activity



95% control crabgrass
LD_{50} = .05% saltmarsh caterpillar
LD_{50} = .05% black bean aphid



90% control, postemergence,
of bindweed



20% control southern armyworm

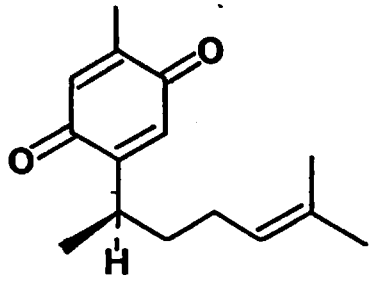
potent insecticide, which functions in an unknown way. But it is not competitive with existing products. More may come from this investigation.

In 1979-80, we began a fruitful collaboration with FMC Corporation. FMC biotested 79 compounds in a variety of assays. Our association with FMC was during the last year of this project, and we still await the testing results from 38 compounds submitted in May, 1980.

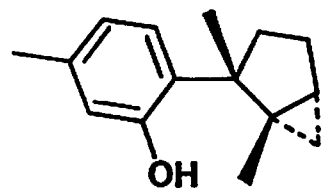
The results of agrichemical testing are summarized most effectively in figure 1, which shows the structure and bioactivity discovered. Some of these compounds are still being evaluated, and this process will probably require several years to complete.

Figure 2 is a summary of the results we have obtained in our collaboration with Professor Jacobs. Several of the 95 compounds submitted are in the stage of continuation testing, and we are most excited about our cytotoxicity results. We plan to expand upon these results in the coming year.

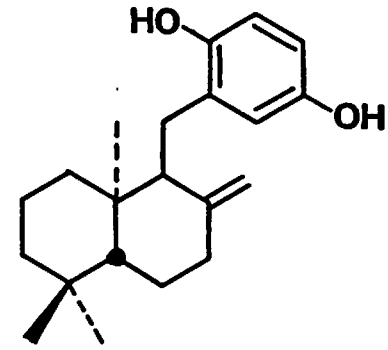
Figure 2. Active Compounds in Pharmacological Testing



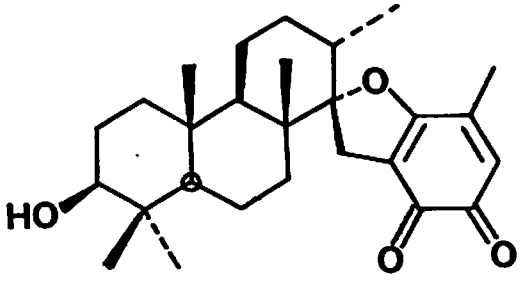
cytotoxin
LD_{50} = 4.0 ppm
fungicide MIC = 30 ppm, ringworm
(*Trichophyton mentagrophytes*)
(*Trichophyton mentagrophytes*)



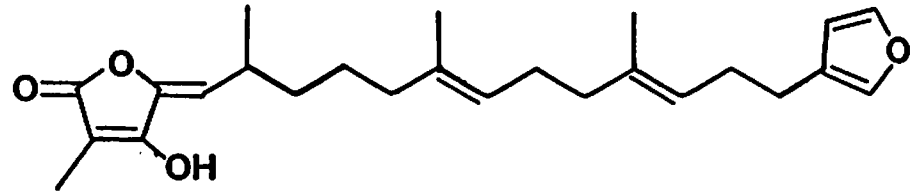
fungicide, MIC = 30 ppm
against ringworm



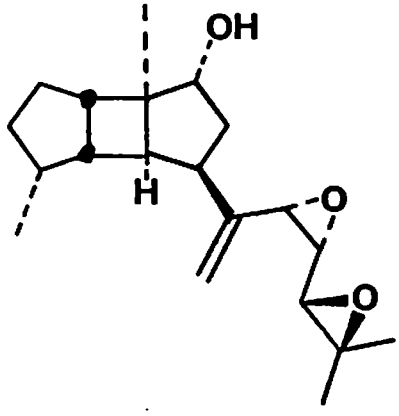
cytotoxin, LD_{50} = 1.0 ppm



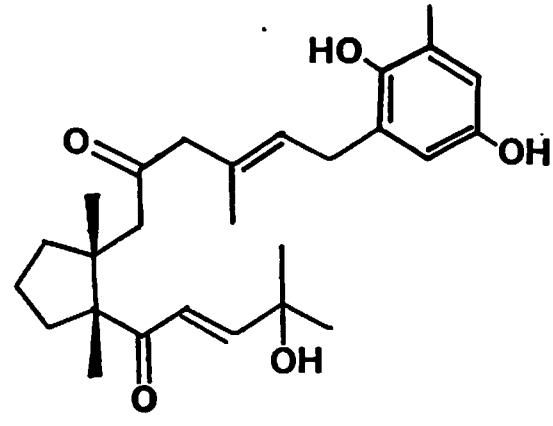
cytotoxin LD_{50} = 2 ppm
inhibitor of tubulin polymerization
diuretic activity



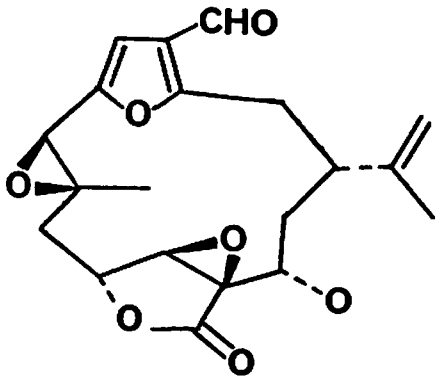
fungicide, MIC = 30 ppm, ringworm



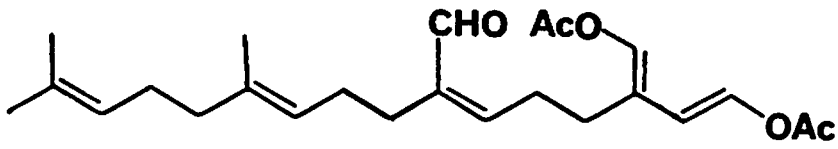
cytotoxin, LD_{50} = 1.1 ppm



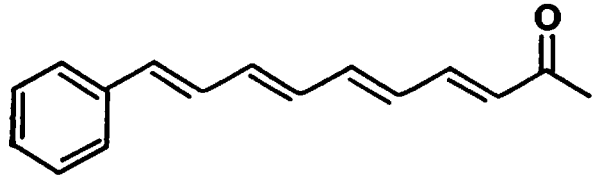
cytotoxin, LD_{50} = 4.0 ppm



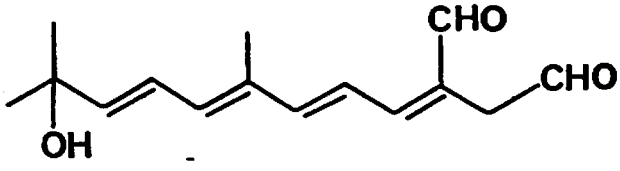
neurotoxin, potency comparable with curare



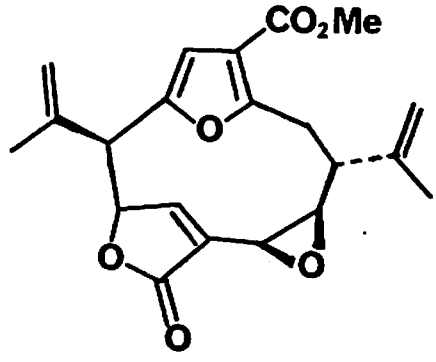
cytotoxin, LD_{50} = 16 ppm



cytotoxin, LD_{50} = 16 ppm



cytotoxin, LD_{50} = 4.2 ppm



cytotoxin, LD_{50} = 4.0 ppm

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Cooperating Organizations

FMC Corporation
Stauffer Research Laboratory
Syntex Corporation
Zoecon Corporation

Marine Plants as a Source of Insect Growth Inhibitors

UC Santa Cruz
R/MP-14
1978-80

Phillip Crews

The management of destructive insects continues to be a challenging problem in agriculture:

> All over the U.S. and in many areas around the globe, bugs are on the march, relentlessly not only retaking the ground so recently won by Homo sapiens but also making new advances. Aided by Government restrictions on pesticides as well as their own growing immunity to the chemicals and benefiting further from the miscalculations and complacency of their human enemies, insects seem well on their way to fulfilling the chilling prophesy of *The Hellstrom Chronicle*... (*Time* magazine, July 12, 1976)

Our initial project goal was to explore seaweeds as a source of new insect-control chemicals. We chose to study red seaweeds of the order Gigartinales because their crude extracts showed initial promise as inhibitors in antidevelopment assays with four common insect pests. Numerous halogenated terpenes were characterized and carefully evaluated. Towards the end of this project, potent pharmacological activity was also observed for these and other marine-derived natural products. Consequently, some of our efforts were shifted to exploit this new lead, and some worthwhile results were generated.

The Zoecon Corporation, which has as one goal to discover "bio-rational" insect control agents, was an important collaborator. Over a two-year period we submitted more than twenty extracts and fifteen purified compounds to their assay program. The seaweeds of the Plocamiaceae were pinpointed as yielding compounds combining both significant bioactivity and novel structures. Our most significant results are shown in table 1, which compares composite bioactive results from compounds **1** to **10** (figure 1) with commercially important agents. It is significant that the "composite" activity from *Plocamium* products is well within the range of activity observable for commercial agents (Staal, Zoecon, pers. comm.). These results implied that the study of new synthetic derivatives based upon the above structures would lead to new compounds with even greater potency.

Concurrent with the above effort, we found

Table 1
***Plocamium* Products vs. Standards**

	Manduca Tobacco Hornworm Larvae (μg/L)	*Musca* Fly Adult (μg/female)	*Aedes* Mosquito Larvae* (ppm)	*Musca* Fly Larvae* (μg/L)	*Heliothis* Tobacco Budworm (μg/L)
Plocamium (composite)	1.8	3.2	.0054	92	4.8
Padan	22.0	-	3.2	-	-
Peramethrin	.029	.029	-	.35	.018
Methoprene	>100	>1000	.0002	.004	>1000
Precocene II	>1000	-	-	-	-
Taxophene	32	10	-	1	>100
BHC	>100	.062	.14	-	4.3

that several of the seaweed products possessing insect growth inhibition were also pharmacologically active (see the report for project R/MP-21). Thus we shifted our efforts, and began a collaboration with Dr. Jacobs to locate new pharmacological leads. At the same time we had access, from other work in our lab, to an expanded array of coral reef organisms, including both red seaweeds and soft-bodied invertebrates.

Some initial positive results from pharmacological testing came from temperate seaweed products. The novel *Plocamium* terpene Violacene **(1)*** and its synthetic derivative **11** were quite active and are now among a selected group of "compounds under current investigation" because of potent activity that they exhibit in Jacobs's rat hemidiaphragm assay (see report for project R/MP-15). *Plocamium* derived **6** and *Laurencia* derived pacifenol **12** have shown marked ability to inhibit cell division in Jacobs' sea urchin assay, and they are among "compounds retained for further investigation." A soft coral diterpene **13** was extremely active in Jacobs's rat hemidiaphragm assay, and it also is being retained for additional study. We isolated aeroplysinin-1 **14** and derivatives **15-18** from coral reef Caribbean and Pacific sponges. Because **14** has emerged as one of the best leads in the National Cancer Institute's marine animal extract program (Douros and Suffres, 1980), we have forwarded gram amounts of this and smaller amounts of the other compounds to Jacobs for evaluation in the sea urchin assay

*For this and all succeeding boldfaced numbers, please refer to corresponding boldfaced numbers in figure 1.

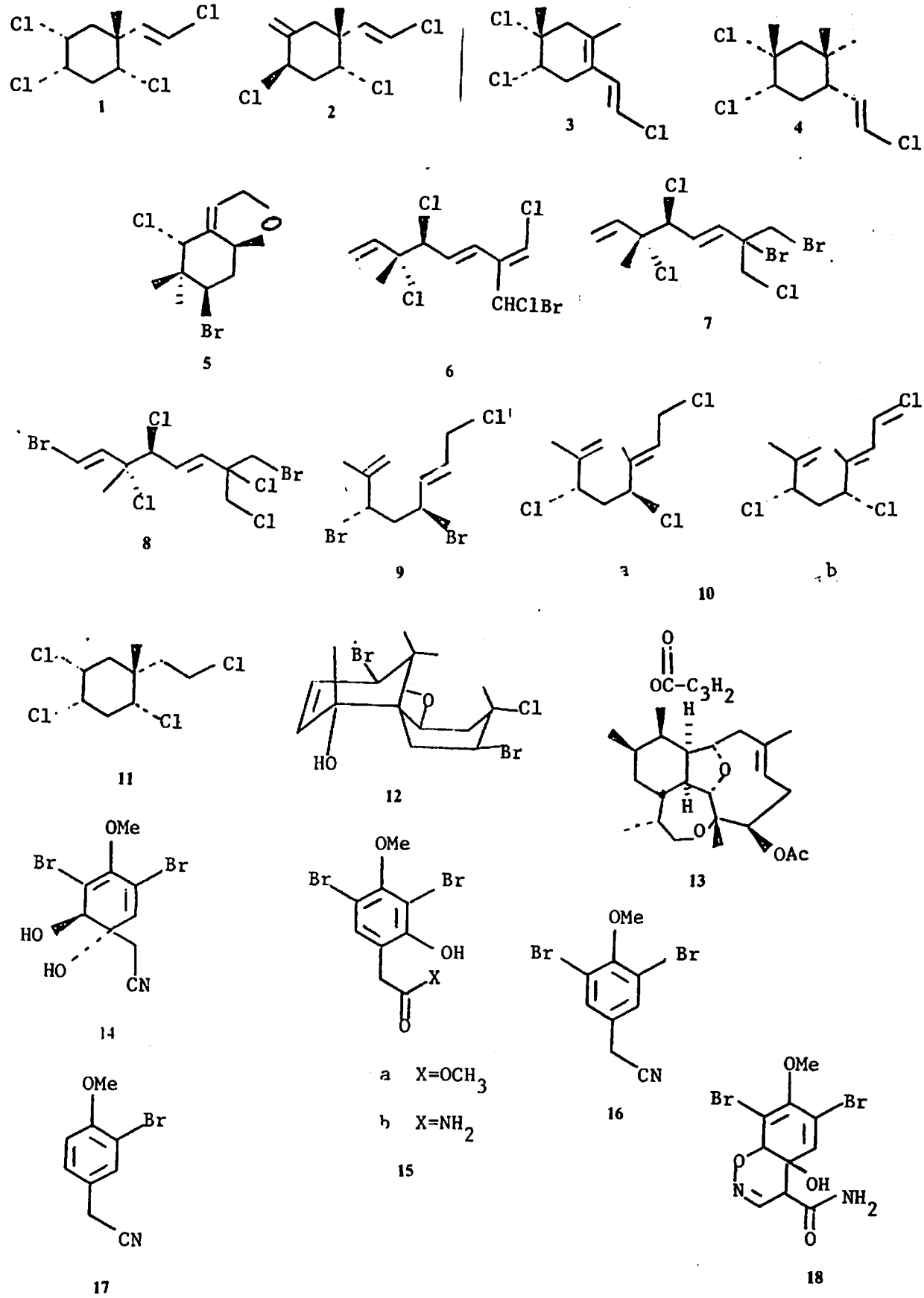

Figure 1.

program. A black Caribbean sponge yielded plakortin and epiplakortin (Stierle and Faulkner, 1980) as major components in amounts varying with collection depth. An extract from this sponge showed very high activity in the urchin egg assay, while neither of the major components is active in this assay. The numerous minor components are currently under chemical study (Newburger and Crews, research in progress).

During the period of this grant we participated in National American Chemical Society symposia, presented invited seminars to various universities and industrial laboratories in the western United States, participated in a special workshop of the Undersea Medical Society, and participated in a film, "The Search For Solutions--Trial and Error," aired on Public Broadcast System (PBS) in August 1980.

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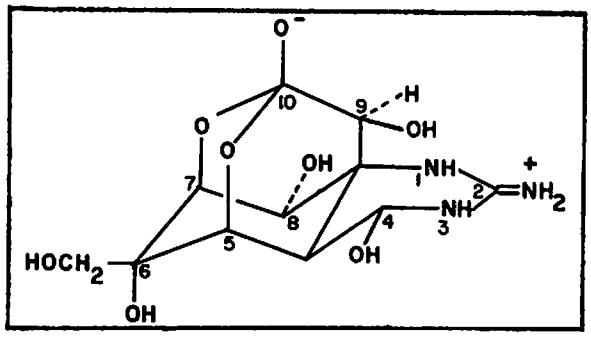
Cooperating Organizations

Syntex Corporation
Zoecon Corporation

Neuronal Blocking Substances from California Gobiidae

Frederick A. Fuhrman

Marine plants and animals are potential sources of new drugs and other pharmacologically active substances. One of these is tetrodotoxin:



This was originally isolated from puffer fish (Tetraodontidae) and is now known to occur in newts of the genus *Taricha* (Mosher, Fuhrman, Buchwald and Fischer, 1964), an oriental goby (Noguchi and Hashimoto, 1973), certain central American frogs (Kim et al., 1975) and an octopus (Scheumack et al., 1978). Tetrodotoxin bonds to a receptor on nerve membranes, and specifically blocks the passive movement of Na^+ across these membranes, thus blocking conduction in axons (Narahashi, Moore and Scott, 1964; Takata et al., 1966). Such blockage, of course, results in local anesthesia, but tetrodotoxin itself is too toxic and too diffusible to be clinically useful as a local anesthetic.

Compounds of this type, however, are prototypes for new local anesthetic drugs and are also highly specific tools for biomedical research. The only other known comparable compound is saxitoxin, the paralytic shellfish poison from *Gonyaulax*. At least six toxins closely related to saxitoxin have been identified in *Gonyaulax* (Oshima et al., 1977). In contrast, only one naturally occurring chemical derivative of tetrodotoxin is known: chiriquitoxin from the frog *Atelopus chiriquiensis* (Kim, Brown, Mosher and Fuhrman, 1975).

Attempts to prepare pharmacologically active derivatives of tetrodotoxin have been generally unsuccessful, and therefore there is a compelling reason to search for such analogs in nature. Some years ago we obtained preliminary evidence for the presence of tetrodotoxin-like, neuronal blocking substances in three species of California goby (Elam, et al., 1977). The most promising source of these is *Gillichthys mirabilis*, the longjaw mudsucker, and this project was designed to further investigate it.

Materials and Preparation of Extracts

The fish, *Gillichthys mirabilis*, were obtained first from sloughs in the southern end of San Francisco Bay (Alviso). When extracts of these were found to be only slightly toxic, additional fish were obtained from near Newport Bay (Oceanside). Representative specimens were identified by Dr. Margaret Bradbury of San Francisco State University. In all, there were 576 fish from Alviso and 90 from Oceanside. They were anesthetized with CO_2 at 5°, and the livers and ovaries (including eggs) were removed.

The tissues were separately homogenized in a Waring blender and brought to pH 5 with acetic acid. The homogenates were dialyzed against distilled water through Spectropor #2 tubing at 5°C in a rotary apparatus. The external solution was changed five times at intervals of 12 to 24 hours. The pooled dialysates were lyophilized to dryness and extracted with methanol. The methanol-soluble fraction was dried in vacuum and dissolved in water.

Results

The solutions were assayed by injection into mice (method: Wakely, Fuhrman et al., 1966), with the results indicated in table 1. In contrast

Table 1

Tissue	Source	Weight	Tetrodotoxin Equivalents	
		(g)	Total μg.	μg/g
ovaries	Alviso	43	<1.7	<0.04
ovaries	Alviso	62	<1.7	<0.03
ovaries	Oceanside	15.5	<1.7	<0.11
liver	Alviso	70	18.0	0.25
liver	Alviso	101	1.5	0.001
liver	Oceanside	13	<1.7	<0.14
ovaries and livers	Alviso	236	16	0.07

to these results, the ovaries of *Taricha* contain about 15 μg/g. tetrodotoxin, and the ovaries and liver of puffer fish (*Fugu*) contain up to 1000 μg/g.

Because of the extremely small amounts of tetrodotoxin-like material present, all samples were pooled for further work. In addition, the

dialysands were extracted with methanol and with water (Goto et al., 1965) in an effort to recover more active material. None was found.

The pooled samples were chromatographed on a column of Biogel P-2 and eluted with pyridine-acetic acid buffer at pH 5.4 (Kim, Brown, Mosher and Fuhrman, 1975). The elution volume at which tetrodotoxin would appear was determined using authentic tetrodotoxin. Fractions before and after, as well as that corresponding to tetrodotoxin, were collected.

These were lyophilized and bioassayed. The toxicity of all samples was extremely low. The largest fraction contained a total of less than 1.4 μg tetrodotoxin-like material.

The solids were dissolved in D_{20}-CD_3COOD for proton NMR spectra using a Varian XL-100 spectrometer in Fourier transform mode. Tetrodotoxin itself has a highly characteristic proton NMR spectrum with a downfield doublet (δ5.91 ppm, J=9.5 Hz) coupled to an upfield doublet (δ2.76 ppm, J=9.5 Hz). The largest fraction from *Gillichthys* obtained here showed a slight suggestion of these doublets, but the amount of material was not sufficient to make further studies practical.

The pair of doublets in the NMR spectrum of tetrodotoxin are attributable to adjacent protons on C-4 and C-4a. Attempts to prepare pharmacologically active derivatives of tetrodotoxin have generally resulted in an anhydro bridge between C-4 and C-9 with loss of biological activity. We had hoped that the tissues of *Gillichthys* would yield one of the following:

1. A toxin containing the basic skeleton of tetrodotoxin that might prove to be a useful analog. (In this case extracts should have been toxic and the NMR spectrum should contain the characteristic doublets of tetrodotoxin.)
2. A nontoxic analog of tetrodotoxin. (In this case the NMR spectrum should have been characteristic of tetrodotoxin even though the extracts were not toxic.)
3. A toxin lacking the tetrodotoxin skeleton.

Since the extracts obtained were neither toxic nor had spectra characteristic of tetrodotoxin, we must conclude that the concentrations of toxic and/or tetrodotoxin-like compounds are too low to make identification feasible with available methods.

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Cooperating Organizations

San Francisco State University (Professor Margaret Bradbury)

Antiviral Compounds from Algae

UC Berkeley
R/MP-20
1978-80

Neylan A. Vedros, Melvin T. Hatch, and E. Frank Deig

The discovery of antiviral material active against herpes simplex virus types 1 and 2 (HSV-1 and HSV-2) in selected species of marine red algae has been documented in earlier publications. The soluble fraction of crude aqueous homogenates of these algae could prevent active HSV infections in susceptible cell cultures and experimental animals, but under the conditions used was not therapeutic for established HSV infections in mice. When the extracted materials were tested against a wide spectrum of other viruses, the antiviral effect in cell cultures was essentially restricted to HSV. Extract from one algal species (*Constantinea simplex*), however, interfered with Coxsackie B5 replication.

During early experiments on the action mechanism of antiviral material we found that such material did not inactivate HSV directly. Instead, it apparently interfered with an early step in the infection of susceptible cells. Within a suitable concentration gradient the antiviral material, both in cell culture and in experimental animals, gave linear dose-response data when tested for protection against a uniform challenge dose of HSV. Recent work has shown that the antiviral material may also interfere with the release of newly synthesized virus from cells.

Sonicated algal extracts containing antiviral material were remarkably free of toxicity when dialyzed before use. Without dialysis, such preparations were highly toxic and often showed hemagglutinating activity toward mouse erythrocytes. Toxicity (and antiviral potency) increased, within limits, as the extraction time was increased. Attempts to recover the toxic factor from the dialysate were not successful. Further work in this area is needed before this factor is understood and its relationship, if any, to the antiviral substance is identified.

The soluble fractions of crude algal homogenates were found to be complex mixtures containing several sulfated polysaccharides and proteins. The polysaccharides fraction was active against HSV in cell culture but not in experimental animals. Treatment of the crude extracts with proteolytic enzymes such as pronase destroyed antiviral action in animals. It seemed likely, therefore, that protein was required for antiviral action *in vivo*, whereas the polysaccharide fraction alone was sufficient for activity *in vitro*. Recent studies have indicated that the polysaccharide may play some role in protecting animals against HSV. The antiviral activity of selected protein fractions was enhanced after combination with polysaccharide fractions from the same plant.

Polysaccharide's role in enhancing *in vivo* antiviral action may be as a stabilizer of active proteins. We observed that the antiviral action in the protein fractions deteriorated rapidly during storage at temperatures of -20 or 4°C. We also have evidence that the antiviral material is very stable in the intact plant. However, once the algae are disorganized by homogenization, the stabilizing forces appear to deteriorate. Perhaps compartmentalization in the plant is a requirement to insure maximum stability, and when these compartments are broken up, the active polysaccharide is needed to confer stability to active antiviral proteins. We also have obtained some evidence that when infant mice were treated with antiviral material 2 or 24 hours prior to infection with HSV, they were protected. However, if the antiviral was administered 96 or 120 hours before infection, the mice were completely susceptible. This may be further evidence for the unstable nature or rapid elimination of the active substance when administered *in vivo*.

Immunization of adult mice with crude algal extracts containing antiviral material produced antibody capable of forming distinct bands with the homologous extracts in gel double diffusion. However, we have not as yet shown whether or not the active substance protecting animals against HSV is itself antigenic. We have, however, observed in a preliminary study that antisera from mice injected with antiviral crude extract passively protected infant mice prior to HSV challenge. Further studies in this area are needed. In addition, we are currently attempting to determine if adult mice, injected with antiviral material as described above, are resistant to dermal HSV infections using the skin lesion model described in our earlier studies.

During this study we have clearly demonstrated that antiviral action from algal extracts differs in the *in vitro* and *in vivo* models. Currently, studies are in progress at Syntex Corporation to isolate the active substance and definitively characterize it chemically. If these studies are successful, we may achieve an antiviral agent with real potential as a therapeutic/prophylactic agent in human herpes simplex infections. With this in mind, we have attempted the laboratory culture of two species

of marine algae (*Cryptosiphonia woodii* and *Constantinea rosa-marina*) as potential supplements to the natural resource. These attempts were successful, and such algae contained comparable amounts of antiviral activity toward HSV as were found in field-collected plants processed in the same manner.

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Cooperating Organizations

Syntex Corporation

Energy

Earthquake Loading on Large Offshore Structures--An Application of Experimental Data to Practical Structure Forms

Joseph Penzien, Ben C. Gerwick, Jr., and Robert L. Weigel

The overall objective of this project is to provide a rational basis by which the offshore industrial regulatory agencies can assess the safety of proposed offshore structures.

Prior to this investigation there was little, if any, data available on the actual response of large offshore structures to earthquakes. During earlier phases of this project, we have gathered data on the response of a 1:100 scale model of a 250,000-ton submerged tank using three different foundation stiffness conditions, ranging from very stiff to soft, based on an elastic half-space model. Structure response was measured over a range of frequencies and using irregular excitation. The water depth was varied in tests so that depths of submergence (measured from the top of the structure) from 0 to 50 m could be examined. These data have been analyzed for the variation of inertia coefficients with frequency and for coupling between modes.

Our objective for the past two years has been to conduct an additional series of experiments studying the effects of superstructure configuration and spacing of the individual vertical circular cylinders ("legs," "towers") to determine the accuracy of generally used analysis techniques. One particular point of interest has been the effects of interference between the towers (or legs) of a multi-towered structure. This is a three-dimensional effect that is very difficult to handle analytically.

We developed a method of analysis and an associated computer program to determine the hydrodynamic pressure distribution on and resulting added mass for a rigid axisymmetric structure located underwater and subjected to earthquake excitations. In the analysis, the fluid is assumed to be inviscid, but it can be either compressible of incompressible. A three-dimensional finite element model of the fluid is used in the near field of the structure, with transmitting elements at the boundary to represent the dissipation of energy by radiation into the far field. The structure can be excited horizontally, vertically, or rotationally using simple harmonic motion; thus, frequency-dependent added mass coefficients in the horizontal, vertical, and rotational directions can be obtained along with the corresponding coupled coefficients. With these frequency-dependent coefficients, the added mass effects can be determined for any arbitrary excitation using the frequency domain form of solution. Good correlations have been made between the analytical results and experimental results obtained in the laboratory.

To experimentally study the hydrodynamic interaction among underwater vertical cylinders subjected to simulated earthquake motions, we constructed four test models. Each model consisted of a cylinder (4.5" in diameter and 38" long) which was attached to an earthquake simulator (shaking table) through four instrumented columns (5/16" x 5/16" x 1-3/8") to measure resultant force components. All components were made of aluminum. Accelerometers were used to measure translational and rotational accelerations of the cylinders and pressure distributions over the surfaces of the cylinders. Using the shaking table, we completed a series of tests using two cylinders. Some 250 test runs were made. A thorough study of the data obtained is in progress.

We are now improving the design of the experimental system in preparation for future testing.

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Cooperating Organizations

State of California

Seismic Hazards to the Development of Offshore Oil Resources

William A. Prothero

This project has studied the continuing seismic activiy of faults in the Southern California Borderlands region. For this purpose, three ocean bottom seismometer (OBS) capsules were constructed and deployed in the Santa Barbara Channel and Pt. Conception-Pt. Arguello vicinity. In addition to the background-monitoring experiments, two ocean bottom seismometers and eight portable land recorders were deployed to study the Santa Barbara earthquake of August 13, 1978. In conjunction with this work, a refraction study of the Santa Barbara Channel (NSF), a study of OBS site response characteristics (ONR), and a study of the East Pacific Rise seismicity and structure (ONR) have been performed. The OBS electronics system also became a model for a U.S. Geological Survey land-based seismic recorder.

The Ocean Bottom Seismometer Capsule

Figure 1 shows a mechanical diagram of the OBS capsule. It consists of a buoyant instrument connected to a heavy tripod support. It falls freely to the ocean bottom when it is deployed, records for a month or more on the bottom, and is released from the anchor weight at a preset time or when an acoustic recall command is received. The pressure tube is made from 7075-T6 aluminum alloy and has a 15.24 cm inside diameter. Its length is 1.7 m. When either of the explosive bolts shown in figure 1 is fired, the tilt arm rotates and the capsule rises to the surface. Four Benthos® 33 cm diameter glass spheres provide positive buoyancy needed to bring the cylinder to the surface. The flotation spheres are positioned near the bottom of the cylinder so it will rise to the surface in an inverted position. This keeps the main cross-sectional area of the deployed instrument low to minimize current-induced noise. In addition, the transponder remains underwater when the capsule is on the surface, so it can be used as a recovery aid.

Data is recorded in an "event triggering" mode. For long deployments, this is the only option, since tape recorders of small size cannot record continuously for more than a few hours. Digital recording is used for a high quality of signal reproduction. The entire system is controlled by an Intersil IM6100 microprocessor. We decided to use a microprocessor because we desired an instrument with a wide range of possible applications and as much flexibility in the triggering and recording configurations as possible. Table 1 is a general set of specifications for the instrument.

Figure 2 is a block diagram of the OBS electronics, showing all functional components. Output from three seismometers passes through preamplifiers and anti-aliasing filters. The preamplifier gains can be set by the computer. The signals then pass through a series of three gain-of-eight amplifiers. If the highest gain output should exceed .75 of full scale, the overscale logic automatically switches the multiplexer to the next lowest gain output. The status of the overscale circuit can be read into the computer and is recorded on tape with the data. The multiplexer, which chooses the analog voltage to be sampled, has auxilliary channels for battery voltage and temperature measurements. The signal from the MUX is passed through a sample and hold circuit and is digitized to 12 bits accuracy by an Analog Devices

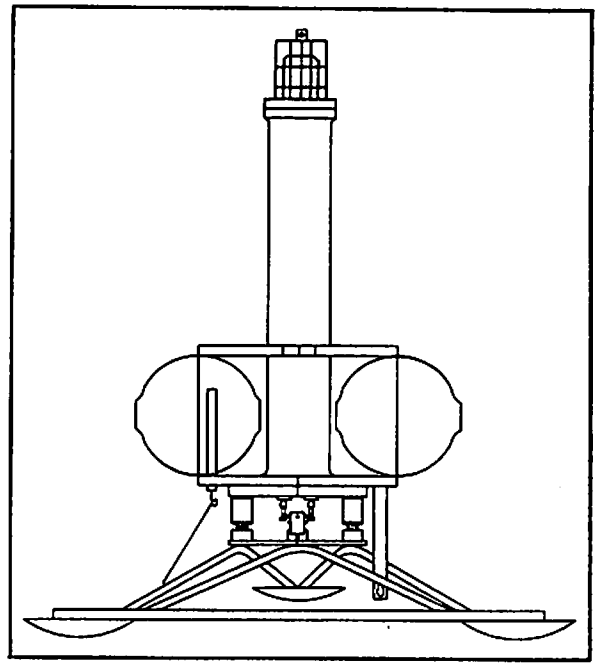

Figure 1. OBS capsule as it rests on the bottom. Electronics are contained within the cylinder, which floats to the surface for recovery of the data. There are no external connectors or wires. When one of the explosive bolts fires, the tilt arm rotates and the capsule separates from the tripod weight. It floats inverted on the surface so that the transponder remains underwater for ranging. Positive buoyancy is provided by four Benthos® 33 cm diameter glass spheres.

Table 1
UCSB OBS Specifications

Mechanical
- weight: 136 kg (approx.)
- descent rate: 1 m/sec (approx.)
- ascent rate: .5 m/sec (approx.)

Pressure case
- tube
  - inner diameter: 15.2 cm
  - outer diameter: 18.3 cm
- endcap thickness: 3.2 cm
  - material: 7075-T6 aluminum
  - coating: hard anodize with dichromate seal and epoxy paint

Release system
- dual explosive bolts actuated by acoustic recall or two independent timers

Sensors
- three component mark products L-25 4.5 Hz geophones gimbal levelled with solenoid-actuated locking mechanism

Recording system
- mode: 12 bit digital with auto gain ranging in 4 steps of 8
- tape recorder: Braemar cassette with four-track head
- data capacity: 1.5 x 107 bits or (81 min for 3 chan at 64 Hz)
- trigger system
  - microprocessor
  - controlled short-terms vs. long-term average
- data memory: 4096 samples
- sample rate: maximum of 128 samples/sec (all 3 channels) with triggering

Timing
- crystal oscillator with internal thermistor for temperature corrections
- *in situ* time corrections possible using acoustic system

Power requirements: .09 watts (continuous)
- power source: Gates Rechargeable "Energy Cells"

Maximum design deployment time
- rechargeable battery pack--2 mo
- lithium battery pack--6 mo

Acoustic system
- ranging: Sonatech transponder - accuracy 3 M (approx.)
- commands: release and diagnostics
- diagnostics: command received, voltages, noise level, number of events recorded, tape runtime (programmable), program restarts, batteries OK
- diagnostic code: one ping = "O", two pings = "1", after diagnostics are transmitted, system pings once per minute synchronized to OBS clock.

Special features and improvements over the previous SIO OBS
1. All checkout, battery charging, and data playback can be performed without opening the capsule at sea.
2. The instrument tube is small enough to fit through a narrow ship's door, and the complete OBS can be launched from smaller boats.
3. Assembly time for new units is minimal because of printed circuit card construction. The mechanical systems are also considerably simplified.
4. No external leads are exposed to seawater.
5. Microprocessor control allows vastly improved flexibility in signal processing and capsule control functions.

ADC 1121 low power A-D. The A-D output is then sampled by the microcomputer for processing and recording.

The microcomputer, as configured for the OBS, consists of a CPU, memory to 16K, watchdog auto-restart logic, programmable read-only memory (PROM) with program loading and auto-restart software, and interfaces. The interfaces consist of (1) A-D and MUX, (2) serial interface to a terminal, (3) digital cassette recorder interface, (4) acoustic system interface, and (5) memory extension interface. The system time base is derived from a 2.097152 MHz crystal oscillator.

It also provides the CPU clock, which is switchable by software to 524 KHz for lower power operation when the system is idling. This clock output is divided to 1 Hz and input to a 24 bit binary counter, which can be read by the computer to obtain an absolute time base reference. The counter is set to zero on the minute with a precise station clock. A separate counter (set to zero at the same time as the 24 bit counter) divides the 1 Hz signal by 60 to provide minute marks for ease of checking the clock rate against external minute-oriented clocks. The zero time is entered into the computer memory at setup time. The operating software then adds it to times derived from the binary counter in the system, providing an absolute time base.

The data and program memory is random access memory (RAM) with both read and write capability. Program memory can be write-protected so that once the program is loaded it cannot modify itself. The watchdog restart circuit consists of two counters, each of which must be reset by the computer every 8 seconds. If not reset, the counters force a control-panel interrupt (a feature of the IM6100), which vectors the program to the control panel PROM. In this system, the restart program reinitializes all interfaces and critical memory locations and restarts the system at an address wired into the

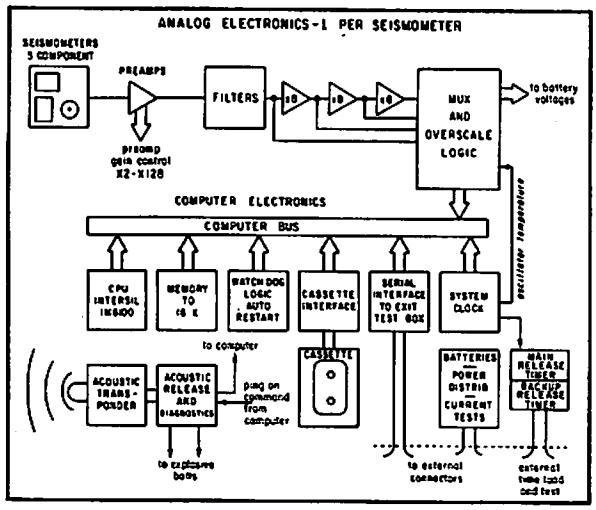

Figure 2. Electronics block diagram. Each seismometer signal is amplified by a computer-settable preamplifier, filter, and gain ranging circuit. The multiplexer (MUX) is capable of sampling the main clock temperature and battery voltages. Data are recorded on a 4-track cassette. The electronics is controlled by an Intersil* IM6100 CMOS microprocessor. Checkout, data playback, and battery charging may be accomplished without opening the capsule.

serial interface card. The serial interface card provides communication between the microcomputer and a terminal. The software operating system uses this facility for setup and diagnostics.

The cassette interface consists of a sequencer that turns on the cassette and requests data when needed. The cassette is a read-write unit, so interface circuitry is also provided to perform "rewind," "backspace," and "read" functions. This enables recorder testing to be performed without opening the OBS pressure vessel.

Power for the system is provided by Gates Energy Cells, which are rechargeable lead acid cells that can be purchased in various sizes and amp-hour ratings. The microprocessor logic system draws 8 ma on slow clock and 23 ma on fast clock from its 6.6 v power supply.

Mechanically, the electronics are on circular double-sided printed circuit cards with plated through holes mounted perpendicular to the axis of a cylindrical tube of 15.25 cm (6 inches) inside diameter. A printed circuit backplane containing 44 pin edge connectors busses the cards together. It is a simple mechanical configuration and works extremely well in practice.

Aftershocks of the Santa Barbara Earthquake

Our most successful experiment was our measurement of the aftershocks of the Santa Barbara earthquake of August 13, 1978. This magnitude 5.1 event caused $7 million damage to the Santa Barbara-Goleta area. Within hours of the main shock, we began to deploy land recorders. Two OBS capsules were deployed for offshore control. Hundreds of aftershocks were recorded within the two weeks following the main event. These data are the basis of the master's thesis of Barbara Bogaert, a geological sciences student at UC Santa Barbara.

Figure 3 shows epicentral locations of a selection of the largest well-recorded events in

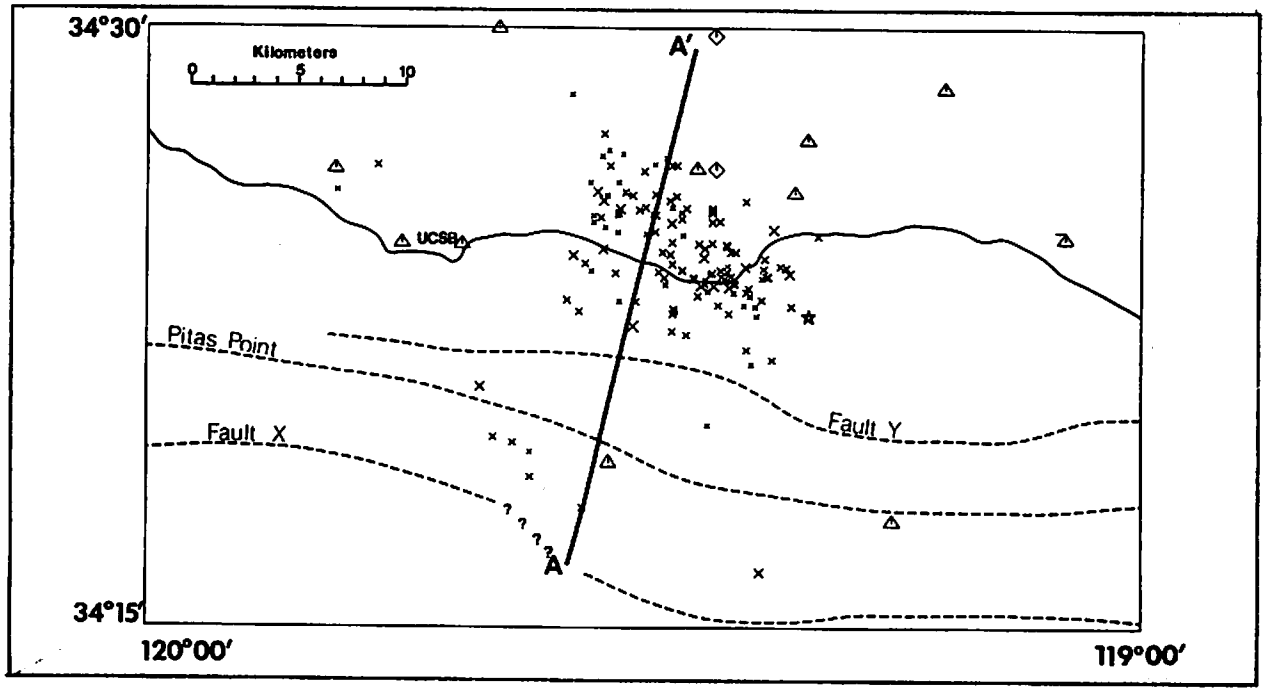

Figure 3. Epicentral locations from aftershocks of the Santa Barbara earthquake of August 13, 1978. The triangles are the station locations, and the X's are epicenters. The star is the location of the main event.

the two-week period following the main shock. The triangles are the recording stations and the X's are the earthquake epicentral locations. Fault X,Y, and the Pitas Pt. fault are from Lee, et al., 1979. Figure 4 shows a cross-section perpendicular to the faulted region (A-A' in figure 3), to show the depth dependence of the aftershocks. The aftershocks are believed to generally occur on the area of slip during the main earthquake. The locations show a generally dipping zone of activity broad enough to be associated with either of the three possible causative faults. This indicates either a broader zone of activity associated with all three faults, or mislocation errors due to the heterogeneous and largely unknown velocity structure in the region.

An important related project has been an NSF-sponsored study of the velocity structure of the Santa Barbara Channel. During offshore shooting to OBS capsules, land stations were deployed in their original Santa Barbara earthquake aftershock locations. Shots to station travel times to these and the permanent network were then used to correct for velocity structure variations. These "station corrections" result in substantially improved epicentral locations and have been crucial to this study. We have also discovered that epicenters located north of Pt. Arguello are often grossly mislocated by the USGS southern California network, since some of our offshore shots have been mislocated on land north of Santa Barbara.

Background Microearthquake Studies

Our attempts to monitor the background seismicity of faults in the Santa Barbara Channel and Pt. Arguello region have been less successful. We have deployed OBS arrays in the Santa Barbara Channel a number of times and once west of Lompoc. The most severe problem has been the very low background seismicity level (often less than one/week) and the abundant shallow-water biological activity, which impulsively shakes the instrument, producing signals that trigger the system and use all the tape. Our last two experiments were aborted because some unknown acoustic source in the channel released one or more of our instruments. The area is highly active with Navy and drilling operations. We will no longer enable acoustic release in this region. Bad weather has also increased the difficulty of operation. There is considerable engineering to be done to solve these problems, and the microprocessor will allow us the most flexibility. Work is continuing under NSF sponsorship. If the problems

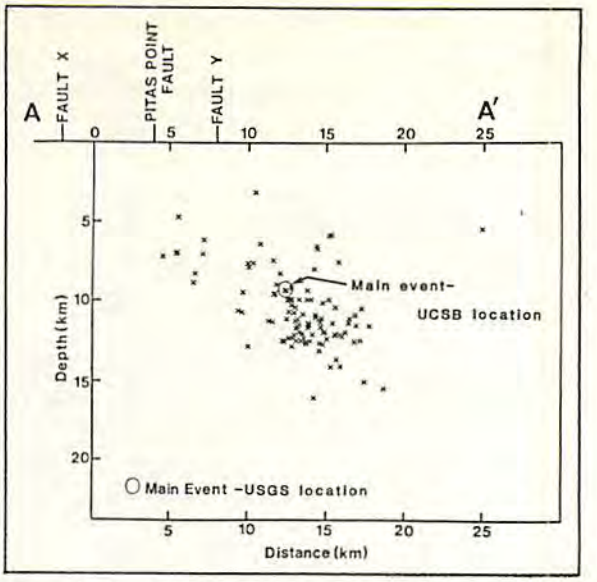

Figure 4. Cross section A-A' (figure. 3) plot of earthquake location vs. depth, showing the projection to faults X, Pitas Pt., and Y.

cannot be solved, the best bet for long-term ocean bottom monitoring lies with permanent, hard-wired stations so that years of data can be acquired with relative (although expensive) ease.

Future Work

In the Santa Barbara Channel region, we have acquired a great deal of data from our refraction and aftershock study. This is allowing us to develop a sufficiently good velocity model and permanent station corrections to accurately locate channel earthquakes using the permanent land-based array alone. This work is continuing under NSF sponsorship. Past earthquakes will be relocated and three-dimensional velocity models will be studied using inversion techniques.

In addition, we have developed a flexible and useful microprocessor-controlled oceanographic instrument. It is being used in the construction of a one-year teleseismic OBS, a UCSB land recorder, and was used as a model for a USGS land recorder.

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Cooperating Organizations

National Science Foundation

United States Geological Survey

Side-Scan Sonar Mapping and Computer-Aided Interpretation of the Geology of the Santa Barbara Channel

Bruce P. Luyendyk, David S. Simonett, and Earl J. Hajic

Our goals in this project ran along two parallel but overlapping tracks. One was to map the exposed seabed geology in selected areas of the Santa Barbara Channel using sonar techniques; another was to develop and experiment with computerized image enhancement of side-scan sonar data obtained from our survey areas. Our survey objective was to produce geologic maps of the seabed and to identify hazards such as active faults. Our image processing objective was to use computer techniques to identify features and to map them in a sonar mosaic.

We worked in six survey areas on four cruises (figure 1). Sea work was done on the

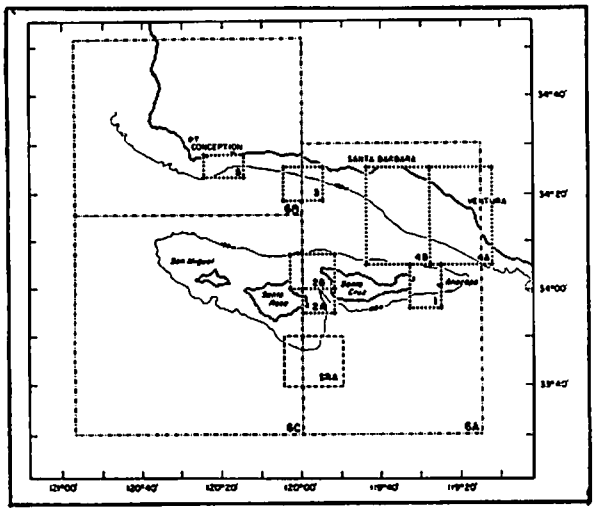

Figure 1. Survey operating areas in the Santa Barbara Channel region. Areas outlined 6 ABC are borders of sheets that have compilations of our ship tracks.

R/V *Ellen B. Scripps* of Scripps Institution of Oceanography in conjunction with seismic monitoring experiments of W. Prothero. Our most successful work was done in Anacapa Passage (Area 1) and the Santa Cruz Channel (Area 2A, 2B). We purchased an Edo-Western 606A sidescan sonar system. Other equipment used included an ORE 3.5 kHz subbottom profiler and a micrologic LORAN-C receiver.

For digital image processing we used the VICAR program package from the Jet Propulsion Laboratory. This software system was originally developed for processing spacecraft imagery. It was fully implemented here at UCSB largely under the auspices of this project.

A survey operation typically involved towing both the side scan and 3.5 kHz fish at 5 knots on a grid pattern with 200 to 500 meter spacing. Loran fixes were recorded every 15 minutes on our first trip, then at 5-minute intervals on later ones. These intervals proved too large for sonar mosaicking, and on our last trip we took navigation fixes every 21 seconds. This was accomplished by interfacing the Loran set to a North Star Horizon II microcomputer and writing each fix to disc automatically. Radar fixes were taken simultaneously during the surveys at 15- to 30-minute intervals. Radar positioning of the ship's track served to calibrate the Loran fixes in given areas to allow for local refraction effects. This offset the Loran positions about one kilometer. The calibrated positions were then put through an averaging filter to produce navigation at one-minute intervals. This navigation set served as the basis for producing range-corrected digital images. Also, during the surveys the side-scan data was analog recorded on magnetic tape. We had problems with the signal-to-noise ratio on the recordings for our earlier surveys, but our last recordings--made on a Racal 4-channel unit purchased under this grant--are excellent. These data are still being processed.

The image-processing procedures have undergone a long evolution of testing to determine the optimum processing flow. Major problems were encountered in handling the sheer volume of the sonar data. In our latest efforts the analog data was digitized at 1.62 kHz and 12 bits in our computer lab (figure 2). These data were then condensed by a two-sample average and converted to 8 bits. The digitized data was then broken into sub-images that were about one-half hour long. Each sub-image contains 3000-4000 scans per side (port and starboard), each 452 samples long in range. Each sample, or pixel, represents just less than one meter in range and was assigned a gray level value from zero to 255 (8 bits), where zero is black. The sub-images were then geometrically rectified to convert time and range data to ground coordinates. This requires the input of sonar sensor depth and navigation series to construct a 360-point spatial control grid for the sub-image. After rectification, the sub-images were contrast

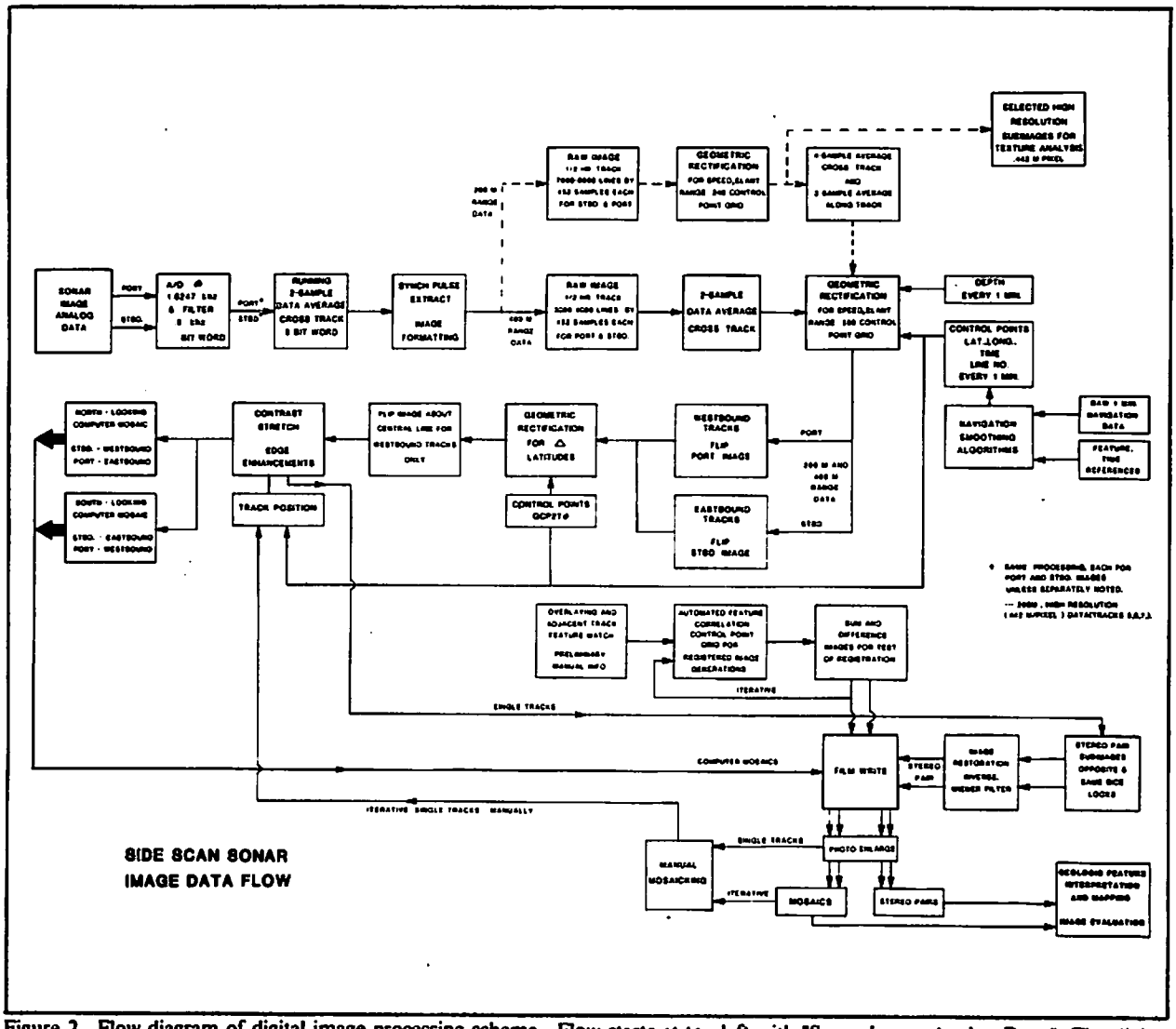

Figure 2. Flow diagram of digital image processing scheme. Flow starts at top left with "Sonar Image Analog Data." The digital output is at center left, "...mosaic." The flow then moves to lower right where mosaics and stereo piars undergo "Geologic Feature Interpretation and Mapping."

stretched. This operation enhances the contrast in the sub-image. Also, the images were processed to enhance edges.

Beyond this step two basic directions were taken. One approach was to perform automatic and manual feature correlation between separate sub-images and then to overlap these data into a new mosaicked data set. The mosaicked digital data set was then output onto a negative via a film writer (figure 2). Another approach was to experiment with sub-image restoration via inverse and Wiener filters. These restored images were also input into the mosaicking stream, but in several instances we also attempted to produce a stereo image from sub-image pairs. This was not successful because navigation control was not precise enough to permit accurate stereo registration, and also the signal quality of the overlapping pairs was too poor.

We processed data obtained from Anacapa Passage in 1978 into a digital mosaic (figure 3). Because these data were taken on a faulty tape recorder, the digital image quality is much poorer than the original paper records (figure 4). Nevertheless, prominent ridges of truncated bedding in anticlines and synclines are displayed (see discussion below). At present we are digitally processing sonar data recorded on the Racal unit. These digital data are of much higher quality (figure 5). By project completion we will produce a mosaic using these data and also test for stereo capabilities. The mosaic we are now constructing is being done in two pieces--one for north-looking insonification, and one for south-looking. This will enable us to use shadows to decipher shapes.

In parallel with the digital image processing of side-scan sonar data from Anacapa Passage, we also analyzed side-scan and 3.5 kHz data from here to construct a geologic structure map (figure 6). The side-scan data shows a spectacu-

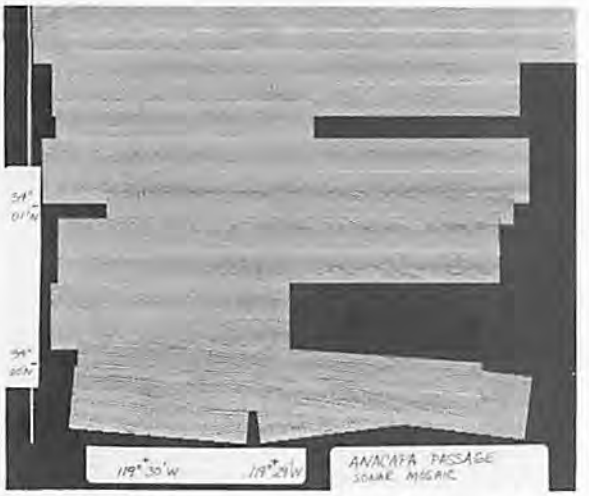

Figure 3. Digital sonar mosaic of data from our July 1978 survey in Anacapa Passage. Processing included geometric rectification, contrast stretch, edge enhancement, and band-pass filtering.

lar display of east-west lineated ridges, which are resistant sedimentary layers exposed on the sea floor in breached anticlines and synclines (figure 4). It was necessary to use the 3.5 kHz subbottom profile to distinguish whether the breached folds are anticlines or synclines. In many places these folds are cross-faulted (figures 4 and 6). Besides manually plotting targets and fold axes on maps, we also devised a system to digitize features on a digitizing table, which writes these data to disc. The disc file was then merged with the navigation series to produce a feature map on a Calcomp incremental plotter. An important limitation to this approach is that the Edo 606A sidescan system uses dry electrostatic paper. This paper cannot be used directly on a digitizing table, for it shields electric contact. Instead we had to make vellum tracings of the original records and digitize these.

Although we have not sampled the folded sediments in Anacapa Passage, they are probably of the Miocene Monterey Formation, which is exposed on eastern Santa Cruz Island. The structure in the Anacapa Passage is notably complex. At first glance it appears that two processes have been operating since the deposition of the Monterey Formation. North-south compression is reflected in an east-west trending anticline-syncline pair, plus several smaller folds in the north-west, and also by east-west trending reverse (?) faults at the south of the study area. A left-shear couple, oriented east-west, has superimposed secondary folding on the larger folds, and also cross-faulted the area with northeast-southwest trending left slip (?) faults. This left shear couple is presumably related to the Malibu Coast-Santa Cruz Island fault system, which trends through here. The north-south compression is related to the Transverse Range uplift, which has been in effect since the

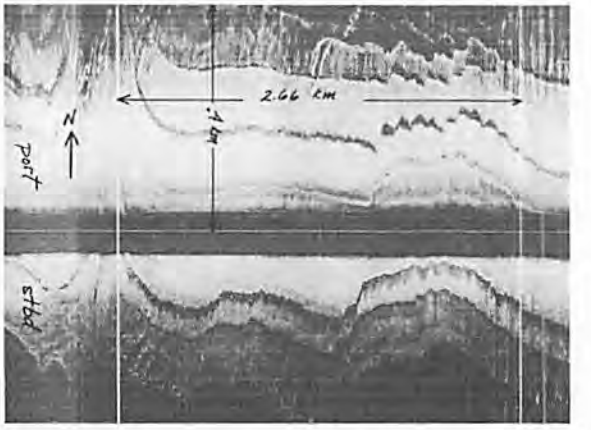

Figure 4. Photo of original side-scan record from Anacapa Passage showing truncated bedding and left-offset faults trending northwest. Location is approximately 23°00'N, 119°29.5'W (figure 3).

Figure 5. Latest digital sonar sub-image from Anacapa Passage. These data were tape recorded differently from those shown in figure 3. The image includes corrections for both slant range and speed changes. Although the image example has not had a contrast stretch, the improved data quality collected on this November 1979 cruise is evident. This image is western half of a starboard, north-looking run. It is located in approximately the west-central portion of Anacapa Passage, a region of complex folding. Scale: 1:16700. Southwest corner of grid: 34.57 N lat, 31.13 W long.

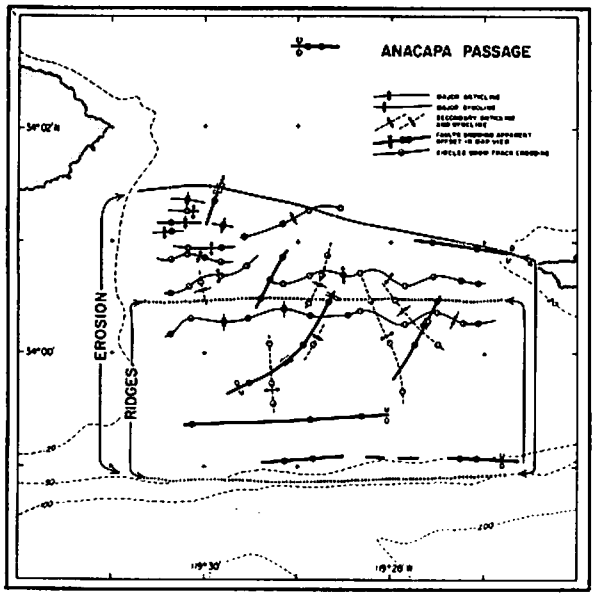

Figure 6. Structure map of Anacapa Passage constructed from side-scan and 3.5 kHz subbottom profile data. Anticlines, synclines, and faults are shown. Circles show location of data control points.

Pliocene. Continued uplift is evidenced by the planed erosion surface in the Passage (figure 6).

We conducted two survey operations on the shelf in an area just east of Point Conception in the vicinity of the proposed Liquified Natural Gas installation above Cojo Bay. In the Point Conception area, numerous structural features and sediment patterns have been detected. Commonly, the spatial relationships of these features are not clear, since repetition of features among neighboring track lines is not found in most cases. It appears that the area is so complex that a clear delineation of features requires a very dense network of data track lines. Previous studies of this area by Dr. Peter Fischer (Cal State Northridge) have had the benefit of a much denser network, but our discovery of several features not included in his compilations indicates that much is yet to be found. Most notable of our findings is sea floor breakage along the trace of the South Branch of the Santa Ynez fault.

In the Santa Cruz Channel study area west-northwest of Frazier Point (west end of Santa Cruz Island) a large northwest-plunging anticline has been found. This feature, mapped over an area of at least 18 square kilometers, has not appeared in available previous mappings, apparently because it is largely obscure in subbottom profiles. The inclusion in this study of side-scan sonar imaging of the sea bottom has allowed us to map out curvilinear ridges protruding through the Holocene surficial sediments. These ridges are the topographic expression of the structure and thus can be used as a surrogate in its delineation. To the south of the anticline, a general change in morphology and the lack of evidence of the anticline are consistent with an extension of the Santa Cruz Island fault north-west about 15 km into the channel. We are optimistic that a careful review of our data and interpretation of additional subbottom data will produce substantial evidence of the fault's course. Additional data were recently provided to us by Dr. Fischer. Although obtained in 1975, these data have never been compiled and analyzed. Considering that the Santa Cruz Island fault displays left-offset, it is apparent that the anticline we mapped is the missing northwest half of the Christi Anticline located in south-west Santa Cruz Island. This anticline consists of Paleocene, Eocene, and Miocene strata, which were folded during latest Eocene to early Miocene time. Its mapped offset in the channel suggests 10 kilometers of left slip since the folding occurred.

In contrast to the relatively thick (typically 6 m), discontinuous Holocene sediments located between the ridges of the topographically expressed anticline in the northwest Santa Cruz Channel, deposits to the south of the inferred fault zone are commonly extensive but thin. In many cases the deposits cannot be distinguished in the subbottom profiles, yet they clearly blanket the surface as seen in the side-scan records. A thickness of less than two meters is therefore inferred. A few faults and folds have been discovered beneath the deposits, and additional inferred faults are expressed topographically, including the presumed extension of the Santa Rosa fault near the coast of Santa Cruz Island. Whereas the trends of faults and folds that are not expressed surficially cannot be determined without multiple subbottom track crossings, the 1975 data may prove critical for interpreting several features.

We have scheduled the following work before project termination on March 31, 1981:

1. Generation of two new digital mosaics of Anacapa Passage
2. Completion of geologic maps in Anacapa Passage, Santa Cruz Channel, and the Santa Barbara Shelf
3. Preparation of a project data report.

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Poster presentation at Marine Sciences and Ocean Policy Symposium, UC Santa Barbara, June 1979.

Cooperating Organizations

Cal State Northridge

Thermophilic Marine Microorganisms from Undersea Hot Springs and Seawater-Cooled Heat Exchangers

UC San Diego
R/E-21
1978-79

John D. Isaacs and Kenneth H. Nealson

Submarine hot springs and the inner surfaces of heat exchangers of seawater-cooled power plants are populated by thermophilic, marine, Gram-negative microorganisms. In the heat exchangers they seriously interfere with heat exchange efficiency. Consequently it is desirable to devise an environmentally acceptable method to control their growth and accumulation.

During 1978 and 1979, our research was directed towards understanding the physiology, distribution, and types of thermophilic bacteria in seawater-cooled heat exchangers and in seawater in general.

Our investigations have demonstrated that thermophilic marine bacteria are ubiquitous in the coastal marine environment. They commonly populate and inhabit submarine hot springs, seawater-cooled power plant heat exchangers, and coastal seawater.

The organisms were isolated from these habitats by enrichment culture techniques using heterotrophic seawater media. Detailed temperature, salinity, and pH gradient experiments show maximum specific growth rates in the range of 55-65°C, 0.25 M NaCl, and pH 6-8. The specific ionic requirements of the microorganisms have been studied, and the results show that all strains do not have specific gross requirements for Na^+, K^+, Mg^{2+}, or Ca^{2+}.

The taxonomy study revealed that all strains are Gram-negative, flagellated, facultative anaerobe, fermentative, non-sporeforming filamentous rods with G+C mole % ratios in the range of 37.6 to 54.6. Studying their morphology under the phase contrast and electron microscope, we found them to be very long, thin filaments, greater than 70 microns in length and approximately 1-2 microns in width. None of the isolates can grow in autotrophic media and none are sulphate reducers. Morphological and physiological traits suggest that the bacteria are members of a homogeneous group that can be classified as a new genus of marine bacteria.

The organisms are sensitive to a wide range of antibiotics such as penicillin, chloramphenicol, and streptomycin, as well as to those that are natural marine products, like plakortin, ilimaquinone and variabilin. There is great promise in using these natural antibiotics to control thermophilic marine bacteria biofouling of heat exchanger pipes without concomitant detrimental effects on the marine environment. However, further investigation is needed to determine the economic feasibility of this method.

We made a detailed analysis of the lipids of several of our bacterial strains. We found that some of these bacteria have very particular lipid molecules that are not readily identifiable and that have to be further studied to determine their specific molecular structure. The possibility thus exists that these particular lipid molecules are partially responsible for the thermophilic capacity of our isolates. Nevertheless, some of the lipids of our bacteria have been typified. For example, the principal phospholipids of strain PB5 have been shown to be mainly phosphotidylethanolamine (75%), phosphatidylglycerol (16%), and diphosphatidylglycerol (3.5%). The methyl esters from phospholipids of strain PB8 were analyzed by gas chromatography, and they consisted of: 16:1 (4.3% wt.), 16:0 (56.2%), 17:0 (<3.1%), 18:1 (30.2%), 19:0 (<3.1%), 20:1 (<3.1%), 22:0 (4.9%) and 24:0 (<3.1%). These data are valuable aids for classifying the organisms.

When the bacteria are grown at different temperatures and salinities there is an apparent random variation in the proportion and types of fatty acids produced. We did not observe a change toward a higher degree of saturation in the fatty acid composition when the organisms were grown at higher temperatures, nor did we observe that the relative concentration of a particular saturated fatty acid, present at low temperatures, increased at high temperatures. These tentative results indicate that our isolates do not possess the adaptation mechanism displayed by other thermophilic bacteria that allows them to synthesize more or less saturated fatty acids as a function of temperature.

Another aspect of our research has dealt with the arsenate metabolism of marine bacteria and yeast. Arsenic metabolism was studied for two marine microorganisms--a facultative anaerobic bacterium, *Serratia marinorubra*, and an obligately aerobic yeast, *Rhodotorula rubra*. Both were cultivated in media with (^{74}As) arsenate (As V), and the products of arsenate metabolism were determined qualitatively.

Both the bacterium and the yeast produced

arsenite (As III) and methylarsonic acid ($CH_3AsO(OH)_2$. In addition to the foregoing, only the yeast produced dimethylarsinic acid ($(CH_3)_2AsO(OH)$ and volatile alkylarsines. In contrast, the bacterium growing anaerobically with cobalamine as a cofactor did not synthesize gaseous forms of arsenic, like methylarsines. Neither organism synthesized arsoniumphospholipids such as those produced by marine phytoplankton or terrestrial fungi. The yeast did not accumulate arsenite, but instead transported some of it into the culture medium and methylated the remainder first to methylarsonic acid and then to dimethylarsinic acid. Finally, the latter compound was methylated further, and volatile alkylarsines were formed. In contrast, the bacterium retained all products of arsenate metabolism intracellularly. Both the bacterium and the yeast, therefore, converted relatively toxic arsenate, the most abundant arsenic compound in seawater, to products that were presumably less toxic. We thus conclude that the principal arsenicals present in seawater are precisely those compounds that we have identified as products of the arsenic metabolism in marine bacteria and marine yeast.

Publications

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Cooperating Organizations

Mexican Federal Government--National Science Foundation
San Diego Gas & Electric Company

A Condensing Centrifugal Compressor for the Distillation of Seawater

UC Santa Barbara
R/E-22
1978-80

M.S. Manalis and Paul H. Lee

Our objective has been to develop a distillation system to produce fresh water from seawater. The system is based on an original concept we call the condensing turbine. We expect to show an important improvement in efficiency over vapor compressors of conventional design because this system is a single synergistic unit.

All input energy is provided through one rotating shaft. The present laboratory models use electric motors. Larger practical models will probably be diesel or steam powered. Each may also be coupled effectively to a windmill.

Planning and Design

Our plan calls for the construction and testing of two quite different prototype designs. We call these Prototype I and Prototype II. They are shown schematically in figure 1 and figure 2.

Prototype I has an axial single stage high velocity centrifugal compressor of the multiple drag-disk type. The compressor has no shroud, but is, instead, surrounded by 12 uniformly spaced vertical copper tubes that act as thin-walled heat-exchangers. These tubes turn slowly about their axes. Stationary internal squeegees spread a metered flow of incoming seawater into a uniform thin film on the inside of the tubes. Seawater boils most efficiently from a thin film, and the mechanical action of the squeegees dislodges those solid deposits that otherwise foul or scale the crucial heat-exchange surfaces. The residual saline concentrate runs down to a reservoir for brine at the bottom of the system. The desired freshwater vapor emerges from both ends of the tubes and flows through many small perforations into the hollow center of the turbine shaft. The flow then continues radially through a second set of multiple perforations into the drag space between the disks, where it is compressed by centrifugal acceleration. It emerges as a rotary wind that flows by the adjacent heat-exchanger tubes and condenses on the outside of them. The turning of the tubes makes condensation more efficient by equalizing the surface usage. Vapor that has condensed on the outside of the tubes runs down to a separate reservoir for fresh water. Another stationary squeegee can be added at the outside of each tube to make this process still more efficient. The heat of condensation flows directly through the thin copper walls and is reused to boil more seawater on the inside.

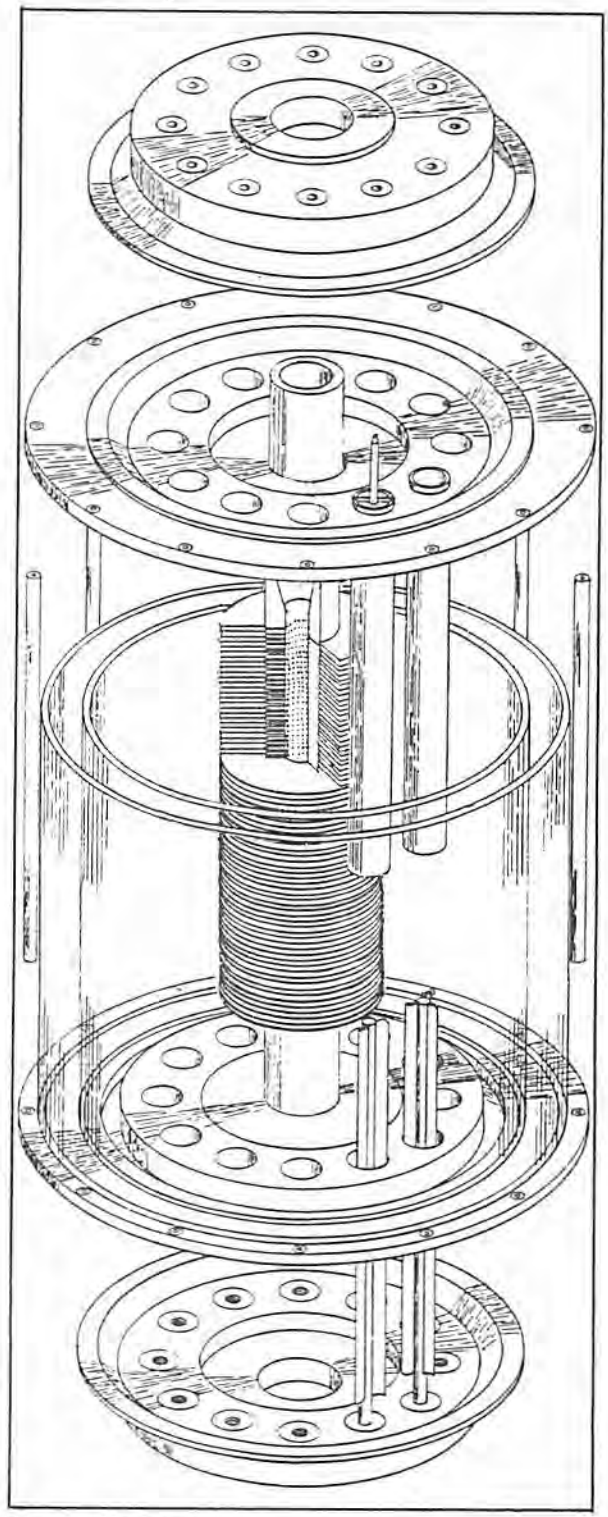

Figure 1. Prototype I.

Prototype II is a simpler device, essentially similar to the one first proposed several years

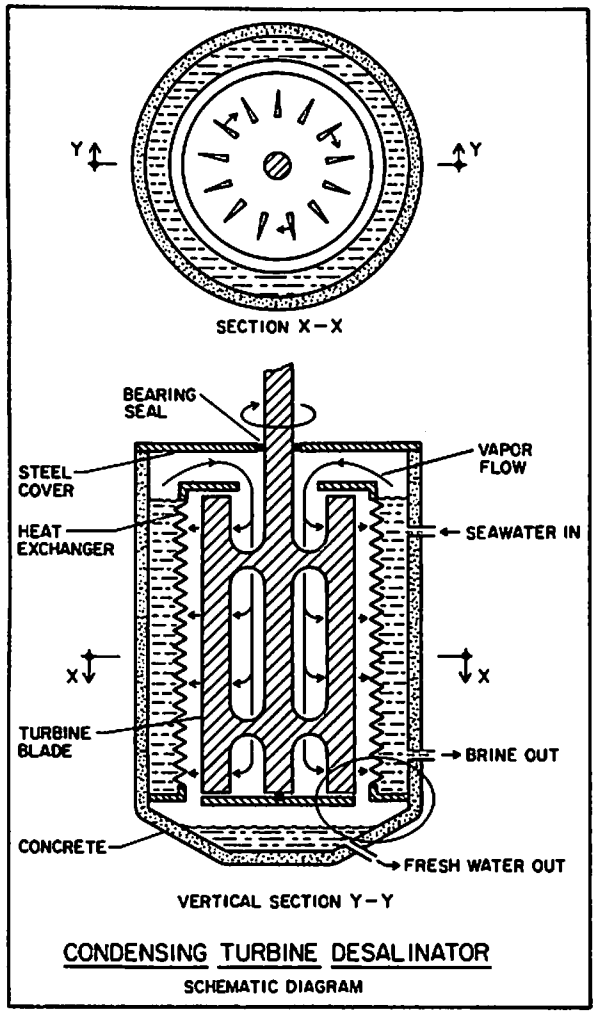

Figure 2. Prototype II.

ago. It also has an axial centrifugal compressor, but the rotor uses straight blades, and the shaft is supported from one end only. Prototype II uses a single large copper bellows as the heat exchanger. Seawater is boiled on the outside surface of that bellows from a concentric annular pool that is in contact with it. At the same time, fresh water is being condensed out of the tangential wind of compressed water vapor that circles the inside of the bellows. The concomitant heat of condensation flows through the thin copper walls to boil more seawater on the other side. There are reservoirs for the storage of concentrated brine and freshly distilled water.

Details of Construction

Prototype I. The completed drag-disk compressor has been machined in a single piece from a rod of 7075-T6 high tensile strength aluminum. It has a hollow central shaft 5 cm in diameter by about 50 cm long. That shaft carries 40 drag-disks 10 cm in diameter. The finished compressor weighs about 5 kg. It will be protected against corrosion by a soft "alodize" coating and dynamically balanced for use at rotational velocities between 30,000 and 50,000 rpm. In contrast with a blade-type rotor design, the smooth edges of the drag-disks should be very resistant to high velocity abrasion by small vapor-borne particles of salt. This was a major reason for the decision to use a drag-disk rotor. The rotor is unusually efficient in this application because of the large ratio of blade area to throughput.

We have elected to place the high rpm shaft bearings outside the low pressure casing to circumvent corrosion and lubrication problems. As a result, we have been able to buy permanently lubricated ultraspeed ball bearings for the compressor shaft. The drive motors are also located outside the vacuum casing, where they can be cooled easily. These design choices have, however, forced us to use frictionless vacuum seals where the high-speed rotating shaft penetrates the case. We have designed and built differentially-pumped labyrinth seals to fill this need.

Two hysteresis-synchronous drive motors are used, one on each end of the rotor shaft. The unmounted components for these motors were engineered and built to our specifications. One hysteretic tube is pressed onto each end of the high-speed shaft, thus eliminating all motor bearings and alignment couplers. We have built integral motor housings to insure compactness, adequate cooling, and accurate fits.

We still need to design an alternating current power source for these motors. An 833 Hz source of 25 to 50 watts will maintain a steady 50,000 rpm, but acceleration to that speed in 10 minutes requires a 300 watt power source that is frequency-programable. This is a penalty one pays for the choice of a high inertia rotor.

The tube that encloses the apparatus is about 30 cm in diameter, and it has a *steel wall about 2 cm thick.* This tube holds the vacuum and rigidly supports the precision components. It is also a shield against destructive failure of the rotor. The manufacturers of centrifuge rotors with comparable stored energy find this form of precaution is both effective and essential.

A stationary stainless steel rod runs axially up the full length of each evaporating tube. Each rod is triangular in section to hold three full-length squeegees symmetrically, and it is bored to carry seawater from its base to a replaceable nozzle at the top. From there, the seawater is sprayed against the inside wall of each tube as it turns. All these components, including the evaporating tubes, can be removed quite simply through the top of the

apparatus for inspection, cleaning, or repair.

For proper process control, each evaporating tube is supplied with seawater by a separate piston of the 12-phase fixed-displacement metering pump that we designed and built for this purpose. The stroke and speed of the pump can be adjusted to fit the experimental operating conditions.

Prototype II. This model will use the same kind of labyrinth seal, bearings, and thick-walled safety shield that has just been described. We have bought a large glass bell jar to hold the necessary low pressure above the single baseplate that supports all the active components. The rotor will be belt-driven by an externally mounted hand-router motor. Although presently running behind, Prototype II may well be finished first because of its greater simplicity.

It is important to note that these prototypes are based on similar fundamental physical concepts. The engineering designs are, however, very different, so that each prototype may well yield different information for future developments. Prototype I is an attempt to maximize the efficiency and reliability of the device at each stage in the distillation cycle. It was subsequently criticized for incorporating complexities into an elegantly simple original plan. Prototype II is a revival of our original damn-the-torpedoes approach. It was the simplest plan we could make to demonstrate the fundamental aspects of this new concept. It had been criticized much earlier, but for the opposite reason: it clearly did not try to optimize each step in the process. Historically speaking, these earlier criticisms were in part responsible for the subsequent evolution of Prototype I. We resolved the matter at the beginning of this year by committing ourselves to testing both prototypes.

Temperature Tolerances of Benthic Marine Invertebrates and Their Relationship to Regulatory Requirements for Thermal Effluent

San Diego State
R/E-23
1978-80

Richard F. Ford and Jon C. Van Olst

Prior to this study, little information was available concerning temperature tolerances of benthic marine invertebrates inhabiting intertidal or shallow subtidal areas influenced by thermal effluent from California generating stations. This lack of information was particularly acute for the warm temperate region of southern California, where the number of power plants is greater than elsewhere on the Pacific Coast. There is critical need for this information in California to assist scientists, the utilities industry, and regulatory agencies in evaluating and controlling effects of thermal effluent. Until recently, primary emphasis was placed on conducting large-scale impact assessment studies, which cannot detect the more subtle effects involved. Specific studies of temperature tolerances and effects, such as those by Adams and Price (1974) and the results of our work (Ford et al., 1978 a,b,c), allow a critical evaluation of the more general results of field studies at generating stations. Without such specific information, these field studies usually fall short of explaining, as opposed to speculating about, the effects involved.

Lack of adequate information about temperature tolerances has, in part, led to the establishment of some arbitrary and seemingly questionable regulatory requirements by the state and federal agencies concerned. One result in California is that new coastal generating stations employ expensive offshore discharge structures. These stations also must regulate the discharge so that it does not produce increases over natural water temperatures (ΔT's) exceeding 4°F (2.2°C) at the shoreline most of the time. Evidence from our study indicates that these may be unnecessary requirements. Properly designed across-the-beach discharge systems, such as that of the San Diego Gas & Electric Company's Encina Power Plant, appear to represent an acceptable alternative from an ecological standpoint and a much more suitable one from the standpoints of engineering complexity and cost.

The purpose of our two-year study was to obtain the needed information about temperature tolerances and related effects on survival, growth, condition, and reproductive characteristics for a representative group of benthic invertebrate species. The work involved (1) studies of upper lethal temperature tolerances, (2) studies of temperature selection or preferences by motile invertebrates, (3) long-term laboratory experiments duplicating cyclic effluent temperature conditions and their effects, and (4) related field studies. These data, in combination with information from other studies, have been used to evaluate pertinent regulatory requirements.

Sixteen species of benthic marine invertebrates common in shallow water along the southern California coast were employed as test subjects in our experiments. These species are listed in table 1. Emphasis was placed on echinoderms, molluscs, and large crustaceans. In each experiment, representative size groups of both juvenile and adult individuals were con-

Table 1
Species of Shallow Water Benthic Marine Invertebrates Employed in Temperature Tolerance Experiments

Scientific Name	Common Name
Echinoid Echinoderms:	
Lytechinus pictus	White sea urchin
Strongylocentrotus purpuratus	Purple sea urchin
Strongylocentrotus franciscanus	Giant red sea urchin
Asteroid Echinoderms:	
Astropecten armatus	Southern sand starfish
Patiria miniata	Sea bat or bat starfish
Pisaster giganteus	Giant starfish
Pisaster ochraceus	Ochre or common starfish
Gastropod Molluscs:	
Acanthina spirata	Angular unicorn shell
Astraea undosa	Wavy turban
Kelletia kelletii	Kellet's whelk
Megathura crenulata	Giant keyhole limpet
Olivella biplicata	Purple olivella
Roperia poulsoni	Poulson's rock shell
Tegula funebralis	Black turban
Tegula gallina	Speckled turban
Decapod Crustaceans:	
Panulirus interruptus	California spiny lobster

sidered separately to evaluate effects of size and age on temperature tolerances. We also conducted separate field studies to evaluate effects of thermal effluent on newly settled individuals and the development of sessile invertebrate communities.

Experiments to determine the upper lethal temperature tolerance limits (96 hour LD_{50} for each species were conducted in closed cycle systems. Separate experiments were conducted following acclimation of animals at different water temperatures representative of seasonal conditions in southern California. We maintained test temperatures by using thermostatically controlled electric heaters in central water baths and by circulating the well-aerated water to the series of large holding tanks where the test animals were kept. We employed standard methods for analysing the data obtained.

Upper lethal temperature tolerances for most of the species considered were well above the maximum temperatures to which they would be exposed in the thermal plumes from generating stations in southern California, even in cases where effluent was discharged directly across the beach. Typical results for two species of intertidal turban snails (*Tegula funebralis* and *T. gallina*) are shown in figure 1. The 96 hr LD_{50} temperatures for these species, following acclimation at 16°C, were 28.4°C and 30.9°C, respectively.

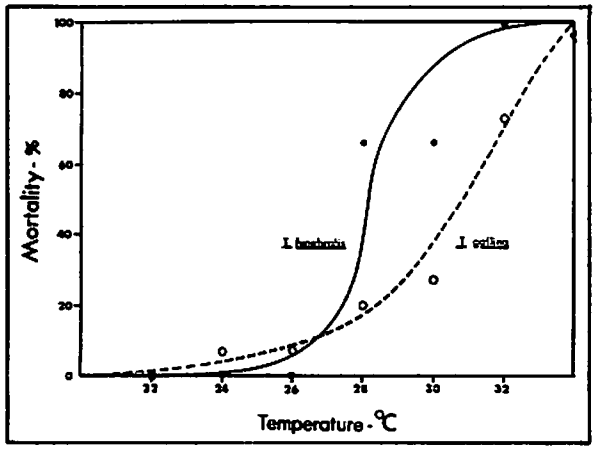

Figure 1. Cumulative percent mortality after 96 hr exposure to six test temperatures for the turban snails *Tegula funebralis* and *T. gallina* acclimated at 16°C. The 96 hr LD_{50} temperatures for these two species were 28.4°C and 30.9°C, respectively.

Long-term simulation experiments of several months duration were conducted in the laboratory, with the 16 invertebrate species as test subjects. The purpose of these experiments was to evaluate combined effects of the effluent's temperature and chemical conditions, and effects of temperature alone, on biological characteristics of these species. Representative juvenile and adult size groups of each species were maintained in large tanks provided with flowing seawater. The survival, growth, body condition, and reproductive characteristics of control groups maintained in ocean water of ambient temperatures were compared to the same characteristics of treatment groups held in thermal effluent or effluent temperature regimes. The treatment conditions employed simulations of varying temperatures and chemical conditions measured at different representative locations in the thermal plume produced by the Encina Power Plant at Carlsbad, California. The experimental system shown in figure 2, employing a cam operated time-cycle controller, was used for these simulation experiments. We employed time-cycle controller systems and pneumatic mixing valves to control temperatures, using cam patterns that reproduced desired temperature regimes in the treatment tanks. The cam patterns duplicated continuous temperature records made in the field.

With the exception of some echinoderms, survival, growth, and reproductive characteristics of most test species showed no adverse effects under the series of treatment conditions. Previous work (Ford et al., 1978c) has shown similar results for other invertebrate species, and also has established that there are no adverse effects associated with chemicals such as residual chlorine in the thermal effluent.

Using a horizontal gradient system, we conducted related experiments to evaluate the temperature selection or preference behavior of the invertebrate test species. The temperature gradients employed as test conditions in these experiments incorporated the range of temperatures to which the animals would be exposed within and outside typical thermal plumes during both cool- and warm-water periods of the year. Typical results are shown in figures 3 and 4.

These temperature preference experiments indicated that all of the invertebrate species exhibited relatively eurythermal temperature preference behavior. This was particularly true for the gastropod mollusc species, which in many cases showed broad ranges of temperature preference, reflected by very irregular or broad, flattened (platykurtic) frequency distributions with mean and modal preferred temperatures relatively close to the low and high ambient seasonal temperatures at which they were acclimated. They inhabit shallow, warm temperate ocean areas where they are subject to fairly wide ranges of temperature, both season-

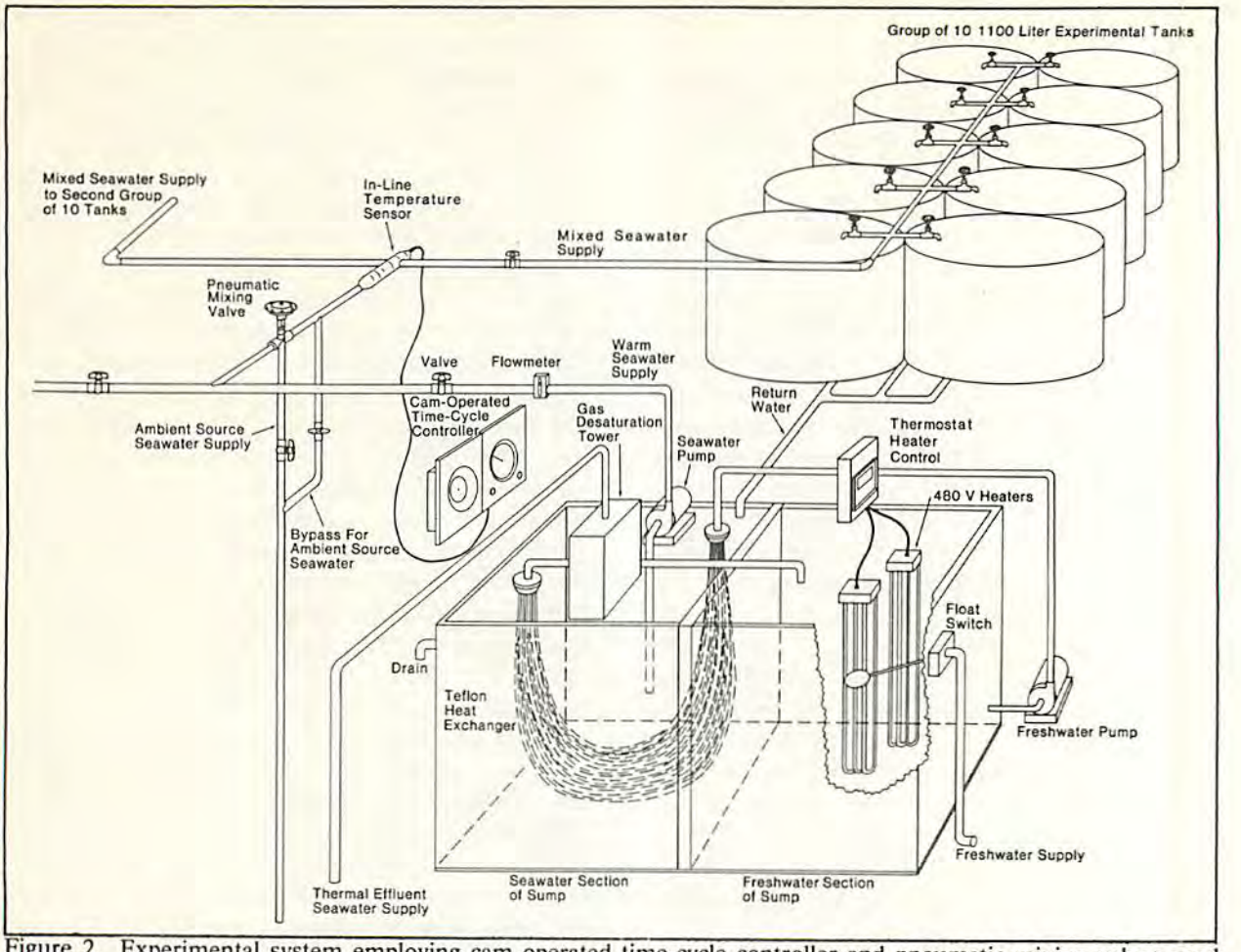

Figure 2. Experimental system employing cam operated time-cycle controller and pneumatic mixing valves used for long-term simulation experiments.

ally and from hour to hour. Thus their relatively eurythermal temperature preference behavior is not surprising. Because of their broad ranges of temperature preference, these species appear to be well adapted for most temperature conditions they would encounter in thermal plumes from generating stations in southern California.

The California spiny lobster (*P. interruptus*) has well-defined temperature preference behavior and can react rapidly to adjust its position in relation to changing or unfavorable temperature conditions (figure 3). Thus its preference behavior is much more like that of most active fishes with moderately eurythermal temperature preferences than that of the other invertebrate species considered in this study. While many of the other species also have well-defined temperature preference behavior, they move slowly and thus could have difficulty adjusting their position to avoid unfavorably high temperatures as the internal temperature structure of a thermal plume changes. However, this probably is compensated by the fact that all of the species have relatively wide ranges of temperature tolerance and temperature preference.

The two sea urchin species (*S. purpuratus* and *S. franciscanus*) evidenced poor temperature sensing ability and related avoidance behavior in wide gradients (7-30°C), which extended beyond their limits of temperature tolerance (figure 4). Individuals of all size groups tended to move into these coldest or warmest sections of the gradient, remained there with no apparent attempt to avoid these adverse conditions, and became torpid or died. This suggests that *S. purpuratus* and *S. franciscanus* probably would have difficulty in sensing and avoiding adversely high temperature conditions (>24-25°C) in a shifting thermal plume. However, such temperature conditions normally are restricted to a relatively small area near the point of discharge. Thus, the number of individuals affected in this way would be quite small.

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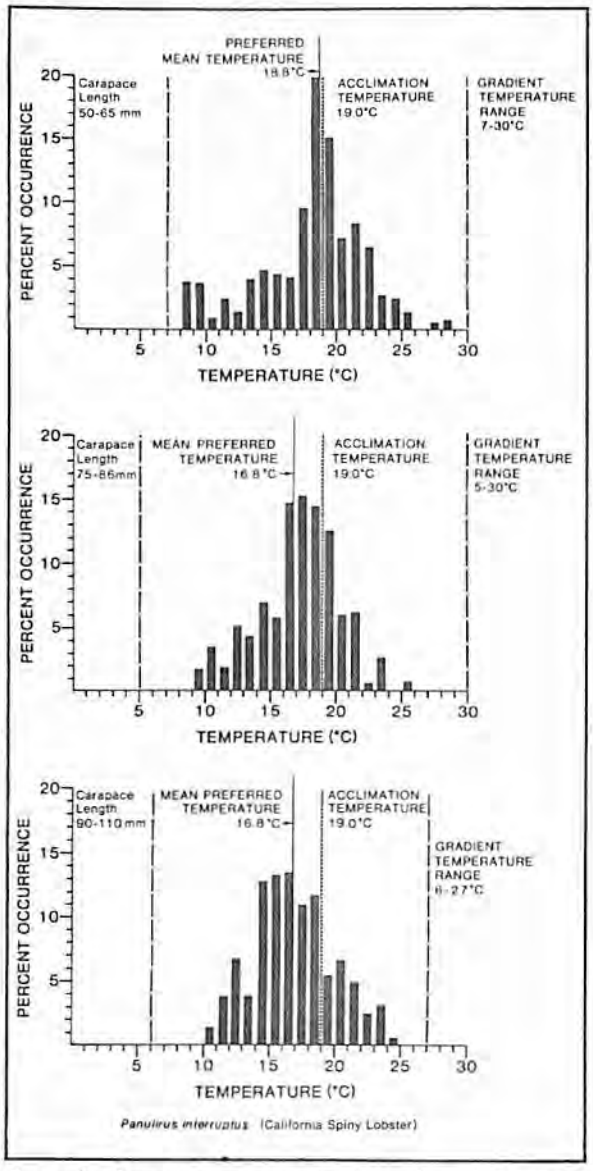

Figure 3. Percent occurrence for three size groups of *Panulirus interruptus* at different temperatures in a horizontal gradient, indicating temperature preference behavior following acclimation at 19°C.

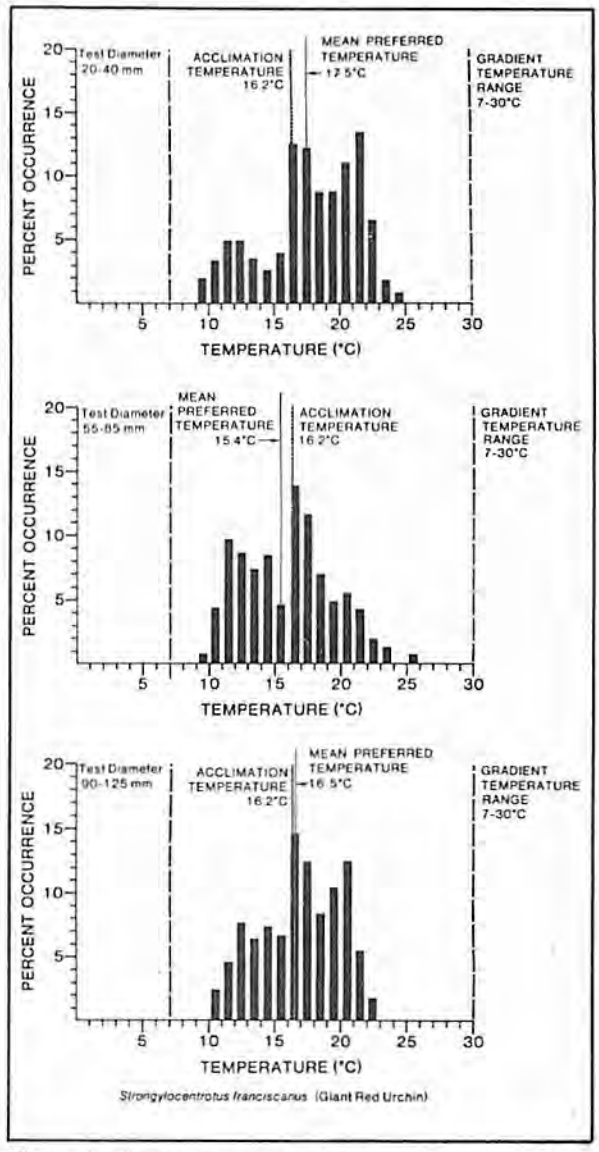

Figure 4. Percent occurrence for three size groups of *Strongylocentrotus franciscanus* at different temperatures in a horizontal gradient, indicating temperature preference behavior following acclimation at 16.2°C.

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Cooperating Organizations

California Water Quality Control Board
Hubbs-Sea World Research Institute
Lockheed Center for Marine Research
San Diego Gas & Electric Company
Scripps Institution of Oceanography
Woodward-Clyde Consultants

Rapid Response

Thermal Variability in Coastal Waters of the Southern California Bight

UC San Diego
R/CZ-31
1978-79

Clinton D. Winant

This project was designed to increase our understanding of the temperature field in southern California coastal waters, and to provide some baseline natural variability criteria for thermal pollution standards in this area. Long time series of temperature taken from current meter moorings in several locations along the coast were statistically analyzed to characterize the seasonal variability and spatial homogeneity of the temperature field in these waters.

The coastal temperature field in southern California exhibits a high degree of spatial and temporal complexity because of the variety of nondeterministic processes that force the field. Solar radiational input, surface wind mixing, upwelling events, major ocean current systems, tides, internal waves, surface gravity waves, and three-dimensional turbulence all act together on different time and length scales to form the observed temperature field. Despite the fact that one can never hope to predict with absolute certainty the ocean temperature field at a given point, several statistical observations can be made based upon past field studies.

There is significant seasonal variability in the coastal temperature field with respect to mean temperature distributions and also with respect to variance levels for frequencies below 6 cpd. Mean surface temperatures have an annual range of approximately 10°C, and surface temperature variance levels, σ_T^2, vary by more than a factor of twenty from summer ($\sigma_T^2 \sim 5°C^2$) to winter ($\sigma_T^2 \sim 0.1°C^2$). In winter months, the temperature field is essentially homogeneous, and consequently the variance in temperature is minimal. Summer months have a mean temperature field that is well described by a two-layer model with an upper layer about 15 m thick and 6°C warmer than the lower layer. At mid-shelf, bottom temperatures are often lower in summer than in winter, providing a source of natural cooling and increased temperature variability.

During the entire year, most of the temperature variability corresponds physically to disturbances associated with the internal wave field, tidal forcing, and subinertial wind forcing events. The tidal temperature response on the shelf includes effects caused primarily by internal waves of tidal frequency rather than by the surface tide.

Temperature changes are well-correlated in the surface waters across the inner half of the shelf except in cases when the warm surface layer is thin. In this circumstance, colder water from the bottom layer may reach the surface in the inner shelf region (total depth less than 15 m). This analysis of temperature observations indicates that on narrow, well-stratified continental shelves most of the temperature variance has time scales of 4 hours or greater and horizontal space scales of 1 km or more.

The natural variability of the coastal temperature field provides a baseline criteria for formulating thermal pollution standards in this area. Large impact may be expected when a thermal plume introduces levels of temperature variability that are greater than the observed natural levels, or when the thermal signature has far different time and space scales than those that are favored naturally. Since the ocean temperature field is best characterized as a random variable field, performance criteria for ocean thermal outfalls should be based upon statistical quantities.

The same processes that shape the behavior of the natural ocean temperature field affect the evolution of thermal plumes. Heat, the pollutant in this case, is an active contaminant in the sense that it not only marks a fluid parcel but also determines to some extent the dynamics of the parcel through associated buoyancy forces. Fluid parcels that contain an abnormal amount of heat will act differently from normal fluid parcels until their heat content roughly corresponds to natural levels. It is likely that most of this adjustment in heat content occurs in time and length scales that are appropriate to the far field. Thus the far field behavior of the thermal plume must be critically evaluated in both the initial design stages of diffuser systems and in the long-term performance of ocean thermal outfalls.

The far field is by definition the part of the fluid field that is independent, or weakly influenced by conditions near the outfall diffusers. The flow in this region is primarily determined by the natural current field on the continental shelf. Performance and design criteria for ocean thermal outfall systems should thus include statistical representations of both the ocean temperature field and the horizontal

current field that vary on appropriate time and length scales.

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Cooperating Organizations

Marine Review Committee of the California Coastal Commission

National Science Foundation

Culture of Marine Bivalves: Effects of the Uptake of Amino Acids

UC-Irvine
R/A-33
1978-79

Grover C. Stephens and Stephen H. Wright

In this project we have been investigating the nutritional contribution that free amino acids in the surrounding medium make to larval bivalves. We have devised techniques to study the net entry of organic solutes from dilute solution as distinct from influx of radiochemically tagged substrates. This is an important distinction, since entry of labelled substrates may be accompanied by exit of unlabelled material. Thus radiochemical studies alone provide no information about net entry.

We have obtained direct and unambiguous evidence for the net entry of known amino acids into larval and juvenile oysters. To my knowledge, this is the first such demonstration for marine larvae. All the age classes of the oyster *Ostrea edulis* that we tested (veliger, pediveliger, and 1.55 mm spat) remove amino acids from seawater media and concentrate them in their tissues. We performed Michaelis-Menten saturation kinetics analysis of amino acid influx on the various age classes of *O. edulis*. Values for the Michaelis constants of alanine and glycine influx were around 35 μM for veliger and pediveliger larvae and around 15 μM in 1.5 mm spat.

We have shown that the bay mussels, *Mytilus edulis*, are capable of removing amino acids from artificial media and concentrating them in their tissues and that they can remove naturally occurring primary amines from seawater.

We are also examining the organic resources in natural waters. We have implemented an analytical technique based on HPLC separation of OPA derivatives of amino acids suitable for seawater analysis. We have data on the qualitative and quantitative composition of a number of water samples.

Finally, we wish to examine the effects of trace additions of known organic substrates on growth and survival of larvae. We have recently succeeded in axenic fertilization and aseptic rearing of larvae of *Crassostrea virginica*. Our access to axenic material permits unambiguous interpretation of the effects of additions to our rearing medium. Aseptic fertilization and axenic rearing of species of *Crassostrea* was pioneered and recently achieved in the United Kingdom. So far as I know, we are the first to achieve this in the United States. The potential utility and power of axenic material in the study of nutritional requirements and the role of specific nutrient substrates cannot be overstated.

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Cooperating Organizations

International Shellfish Enterprises, Moss Landing, California
Moss Landing Marine Laboratories

Histamine Toxicity from Fish Products

UC Berkeley
R/F-43
1978-79

Leonard F. Bjeldanes

The overall objectives of this project were (1) to understand the etiology of scombroid poisoning, which has resulted from consumption of common fish such as tuna, mackerel, and bonito, and (2) to determine levels of toxic components in fish.

There seems to be little doubt that histamine is involved in scombroid poisoning. However, this compound does not appear to be the only cause. Histamine exhibits low toxicity when consumed by humans (Weiss, Robb and Ellis, 1932), and tuna spiked with histamine in amounts that cause poisoning when present in toxic fish causes no symptoms of toxicity (Kimata, 1961).

Efforts to isolate and identify histamine-like substances, notably saurine, from toxic fish have not been successful (Foo, 1976; Olcott and Lukton, 1961). Such substances do not appear to play a general role in fish poisoning.

Several compounds have been reported to potentiate histamine's biological activity in laboratory animals. Of these substances, putrescine and cadaverine occur in appreciable quantities in toxic fish, and in low levels in nontoxic fish (Kim and Bjeldanes, 1979; Mietz, 1977). Effects of these substances on histamine reactions have been observed in the guinea pig or its tissues. Parrot and Nicot (1966) have shown that the peroral toxicity of histamine in this animal is increased by a factor of ten when the histamine is administered 40 min after oral administration of putrescine. The putrescine dosage used was five times that of histamine on a weight basis, and potentiation was not observed on simultaneous administration of the two compounds.

Recent studies have shown that the levels of cadaverine in toxic or decomposed fish are generally several times greater than the levels of putrescine (Kim and Bjeldanes, 1979; Mietz, 1977). These data and the fact that potentiation in the guinea pig was observed only with relatively high doses of putrescine administered prior to histamine (Parrot and Nicot, 1966) suggest that putrescine may not play a central role in histamine poisoning from fish.

Oral administration of cadaverine dihydrochloride by itself revealed a relatively low toxicity in the guinea pig, with an LD_{50} of about 1000 mg/kg and a relatively high minimum lethal dose (MLD) of more than 500 mg/kg. In our studies, a histamine dose of 150 mg/kg caused no deaths in the test group. However, simultaneous administration of histamine (150 mg/kg) with relatively low doses of cadaverine led to a marked increase in toxicity. A dose of 150 mg histamine/kg and 50 mg cadaverine/kg killed 33% of the group, a figure increased to 84% by a rise in cadaverine dose to 75 mg/kg.

The potentiation effects of cadaverine are notably different from those of putrescine. Maximum potentiation is seen on simultaneous administration of cadaverine and histamine. The 40-min interval between doses reported to be required for potentiation with putrescine resulted in a decrease in effect with cadaverine. Thus, in one experiment, a 40-min interval between dosing with 100 mg cadaverine/kg and administration of 150 mg histamine/kg resulted in the death of only 60%, compared with nearly 90% after simultaneous administration of these doses.

A separate experiment compared the effects of simultaneous administration of histamine with putrescine or cadaverine. Animals were treated with 50 mg histamine/kg and either putrescine or cadaverine in a dose of 150 mg/kg. Although with the lag period this combination of histamine and putrescine doses would have been expected to kill all the animals (Parrot and Nicot, 1966), no deaths were observed after simultaneous administration. In contrast, one-third of the animals died in the cadaverine- histamine test group. Finally, at the histamine levels used, potentiation was observed with cadaverine-histamine ratios of less than one. This is in contrast to the 5:1 putrescine-histamine ratio used in the putrescine potentiation studies (Parrot and Nicot, 1966).

The results are consistent with the hypothesis that histamine poisoning from fish products could be due to the potentiating effects of cadaverine.

As an initial attempt to understand the mechanisms of cadaverine potentiation on histamine toxicity, the effects of cadaverine on histamine transport and metabolism in the intestine were studied *in vitro* with isolated guinea pig gut sac.

A known amount of (ring-2-^{14}C)-histamine diluted with non-radioactive histamine was placed in the gut sac, with and without cadaverine. Analysis of the solution outside the gut sac showed the following results:

1. Cadaverine increased rate of transport of radioactivity across the gut wall. After three hours, 33% more radioactivity appeared outside the gut sacs in the presence of cadaverine than in controls.
2. No latent period was observed before the transport of radioactivity starts.
3. The relative effect of cadaverine on transport of radioactivity was greater at low level of cadaverine to histamine and showed no further increase at the relative level to histamine 1:2.
4. The analysis of metabolites outside the gut sacs showed significant increase in the percentages of histamine, imidazoleacetic acid, and acetylhistamine. The levels of 1-methylhistamine and 1-methyl-4-imidazoleacetic acid did not change appreciably.
5. However, the overall picture of metabolism was not changed. Approximate proportions of each metabolite are not changed appreciably.

Therefore, the action of cadaverine on histamine may be due to mechanisms other than enzyme inhibition.

Binding to mucin is reported to be important in maintaining the barrier opposing the transport of histamine across the gut wall. If cadaverine competitively binds to mucin and decreases the available mucin for histamine binding, the equilibrium will shift toward leaving more histamine in free form. We therefore investigated the effects of amines on histamine binding to gastric mucin in solution.

Binding of histamine to mucin was examined by using tracer amounts of (ring-2-^{14}C) histamine di-HCl diluted with nonradioactive carrier histamine di-HCl in pH 3 buffer. The amount of histamine bound on mucin increased with greater concentration of histamine. Saturated binding 2.5 μmole histamine/μmole mucin was obtained at histamine concentration of 0.5 mg/ml, and the binding was shown to be ionic type.

At the condition of maximum histamine binding, the inhibition effects of polyamines were observed. Histamine binding was inhibited by 46.6% by spermine, 25.4% by spermidine, 9.5% by cadaverine, and 11.2% by putrescine. The inhibition increased with the number of amino groups, suggesting that these groups were involved in an ionic bond to the carboxylic group of sialic acid in the mucin.

Amine extracts from canned tuna fish and amine mixtures also inhibited histamine binding to mucin. The basic extract of canned tuna fish showed high activity in the inhibition of histamine binding. The responsible substances are not known. The aqueous extract also showed inhibitory activity. The results are consistent with the proposal that histamine toxicity is potentiated by the effects on gastric mucin of amines in fish.

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

UC San Diego
R/F-44
1978-79

Michael M. Mullin, Reuben Lasker, and F. Kim Devonald

Marine fishes often undergo significant fluctuations from year to year in population sizes and in age distributions within their populations. These fluctuations result from annual differences in reproduction and mortality rates. Both of these processes are affected by a number of environmental factors, as well as by direct and indirect effects of fishing, in cases where fishing pressure is substantial. The relative importance of each of these factors in determining year-class strength (the number of young fish surviving to adulthood each year) is not yet well understood. Data on survival rates of young fish of species from various regions of

the world suggest that by far the greatest part of the mortality experienced by a year class occurs in the earliest stages of the fishes' lives: in the first few weeks--and probably, in fact, in the first few days of their existence.

We have been studying one environmental factor that is presumed to affect growth and survival rates of fish in their early larval stages: the availability of suitable planktonic prey in the waters where the fish are spawned. It has often been suggested that the absence of suitable food, or of high enough concentrations of those organisms, may be the most important factors determining the numbers of fish that survive their first-feeding period (the time when the yolk has been absorbed, and they are just developing the capabilities to hunt and capture their prey). Specifically, we have evaluated the importance of food availability in the survival of the young larvae of the California jack mackerel.

Jack mackerel are among the most abundant fish of commercial importance in the California Current region, and in fact, in all the temperate eastern boundary current regions of the world. Jack mackerel larvae are similar in morphology and food requirements to larvae of most other moderate- to large-bodied marine fishes. Unlike larvae of the smaller sardine or anchovy-like fishes--which are relatively slow-moving, have small mouths, and feed initially on phytoplankton--mackerel larvae (and those of flat fishes, cod, hake, and members of the tuna family) have relatively large mouths, swim energetically, and start consuming small zooplankton on their first day of feeding. Laboratory feeding studies of various fish larvae have suggested that the food densities required for their survival are very much higher (by as much as an order of magnitude) than the average densities of small zooplankton measured in coastal ocean waters by conventional sampling gear. Consequently, it has been thought that most of the high mortality rates of fish larvae might simply be due to starvation.

Although there have been several studies of the natural densities of zooplankton small enough to be consumed by fish larvae, little has been known about the distributions of these organisms on small spatial scales. The sampling methods used in most studies of micro-zooplankton would not permit the identification of aggregations ("patchy" distributions) of these organisms over distances of meters, or fractions of meters, which are important to fish larvae. As patchy distributions on most size scales are the rule rather than the exception for planktonic organisms, it is reasonable to guess that the various kinds of micro-zooplankters might be aggregated in some way. If that were the case, then fish larvae in their daily ambits would not always be exposed only to the low prey concentrations measured by towing pumps and nets through large volumes of water: they would sometimes encounter dense prey patches from which they might be able to obtain the daily rations required for their survival. A patchy distribution of prey could thus greatly increase the chance of any given larva obtaining enough food to survive.

Methods

In order to investigate whether in fact large numbers of jack mackerel larvae in the natural spawning grounds are underfed, we first did a series of laboratory experiments to determine which morphological factors are the best indicators of the feeding condition of larvae in the first two weeks of life. Larvae were reared in the lab for one to three weeks, feeding on constant prey densities ranging from the average densities found in the open sea to very high levels, which would be found only in dense aggregations. Consumption rates varied proportionally with prey density, and larvae in the lower prey density tanks were significantly smaller in all dimensions than better-fed larvae of the same age.

Differences in feeding history could be seen not only in overall growth rates, but also in the body proportions of the young fish. The low-prey-density larvae had smaller heads and much narrower bodies than larvae from the higher-density tanks. Although growth in most dimensions was decreased markedly by lower food intake, the effect on growth in length was somewhat less, and growth rates of the larvae's eyes were only very slightly affected by even major differences in food intake. The differences in relative sizes of the various body parts resulting from the different levels of food intake provide an index for evaluating the feeding condition of larvae collected at sea. An especially convenient aspect of this index is that it does not require determining the age of the larvae.

One additional factor that had to be considered was the problem of larval shrinkage during collection, handling, and preservation. It has recently been widely recognized that larvae collected at sea are subject to an additional cause of very substantial shrinkage beyond that of exposure to preservative solutions. This is the shrinkage that occurs while the larva is in the collecting net, and while the net-collected

sample is being handled prior to preservation. The duration of this collection and handling time can vary from 10 to over 30 minutes. In order to determine appropriate correction factors to use to compensate for the differential shrinkage in body parts during this time, we worked with scientists of the National Marine Fisheries Service Southwest Fisheries Center to analyze the results of laboratory shrinkage experiments in which field net collection was simulated. These experiments demonstrated that preserved body length is a very poor indicator of initial size, while eye diameter is a very good indicator, as eyes of larvae of all sizes shrank by less than 4%, and completed most of their shrinkage in the first few minutes of the simulated net tows.

Because preserved body depth and eye size are both good indicators of live larval dimensions, and since growth in body depth is much affected by food intake, while eye growth rates are only slightly affected, a comparison of body depth to eye size provides an excellent index of the feeding condition of field-collected larvae. To provide additional, independent estimates of feeding success, gut content analyses were done of some larvae from each sampling site in this study.

Results

The new method for evaluating the developmental condition and feeding success of field-collected jack mackerel larvae was applied to larvae 2.5 to 5.0 mm in preserved length collected from various portions of the spawning region off Baja California and southern California. In 1978 and 1979, larvae were collected specifically for this study at stations between 15 and 60 miles offshore. We also evaluated larvae from samples collected between 20 and 120 miles offshore during the 1972 CalCOFI survey.

Preliminary results, based on stations for which all data have been analyzed, are that fewer than 15% of the larvae collected in any of the areas sampled were in poor morphological condition, apparently having been feeding insufficiently to meet their nutritional requirements. Other larvae were in comparable physical condition to well-fed laboratory-reared larvae, which were able to survive and achieve high growth rates in the laboratory. This conclusion was corroborated by the results of analyses of the gut contents. Larvae of the various sizes had feeding incidences ranging from 40 to 65%, and a mean of 4 to 5 prey items in their guts, as compared to 45 to 75% feeding incidences and a mean of 5 to 6 prey in the guts of the well-fed laboratory larvae.

We do not know whether the few poorly developed larvae were initially healthy individuals who failed to find sufficient food, or whether their development was affected by factors other than food availability, such as genetic factors, or disease or injury. Nor do we know how many of the siblings of the larvae we caught had been killed by predators, perhaps because they were weakened by lack of food. However, the fact that the great majority of larvae in these samples had been feeding successfully suggests that starvation is a minor direct cause of the high mortality rates of young jack mackerel larvae.

Cooperating Organizations

National Marine Fisheries Service, Southwest Fisheries Center

Feasibility Study of *In Situ* CPR Using SCUBA-ERR (Emergency Regulator Resuscitation) and Closed-Chest Cardiac Massage

UC San Diego
R/NP-1-8A
1978-79

Nico F. March and John B. West

The growing popularity of water sports and offshore oil exploration has led to increasing fatalities in water. Heart attack, trauma, blackout, and drowning are a few of the circumstances that can lead to cardio-respiratory arrest and possibly death in the water. The conventional method of emergency life support when the heart has stopped is cardiopulmonary resuscitation (CPR). CPR utilizes mouth-to-mouth resuscitation coupled with external cardiac compressions. Although CPR can be performed on land, it was previously considered difficult, if not impossible, to do in the water without solid support for the victim's back.

This project has developed design modifications necessary for transforming a scuba regulator, used by divers for breathing underwater, into an emergency regulator resuscitation (ERR) device. This is the first resuscitator developed for use in and under the water and in other hyperbaric situations. We have also developed techniques for aquatic cardiopul-

monary resuscitation.

A redesigned recording resuscitation mannequin, capable of simulating a human victim of heart attack, drowning, or other cardiorespiratory dysfunction in the water, was developed and tested at the UCSD School of Medicine. The mannequin mimics an unconscious diver in weight, breathing resistance, buoyancy, and movement. It has pressure transducers to measure cardiac compression and proximal airway pressures, and a Gould-Brush Mark data recorder to monitor results. An electrical audio-feedback system allows the rescuer to detect correct sternal positioning, compression depth, and adequate ventilation, and to make corrections. It also allows for single-blind testing in which the rescuer has no indication of his progress, but a data strip is immediately available to the investigator on dry land.

The mannequin was used both in pools and in open-ocean experiments with the U.S. Coast Guard to test the ERR device and to study physiological effects of hand and body positions, flotation characteristics of victims and rescuers, and to determine whether a one-rescuer CPR technique is possible in the water.

The use of ERR with aquatic CPR eliminates some of the awkwardness of providing both cardiac compressions and mouth-to-mouth resuscitation in marine environments. The possibilities for use of ERR are great, both in and under the water, for drownings or with aquatic CPR, as well as on land with conventional CPR, or in instances where mouth-to-mouth may be impractical or aesthetically unappealing. Naturally it will be very convenient for scuba divers, since they can always be equipped with the dual-function regulator.

It is hoped that the use of ERR and aquatic CPR we developed will help lower the mortality rate in marine environments by enabling life support to be given while there is still a chance for the victim's survival.

In August of 1980 the JAMA standards for cardiopulmonary resuscitation and emergency cardiac care were updated to reflect our findings. In short, the statement that CPR was impossible to perform in the water was replaced with a recommendation that it should not be attempted unless one has had special training in the performance of aquatic CPR.

In 1981 the special ERR devices will be available in southern California and the P.A.D.I. International College of San Diego will begin special training of scuba instructors and other rescue personnel in the techniques of ERR and aquatic CPR.

Publications

March, N.F. New techniques in closed chest cardiac compression: aquatic CPR. *Proceedings International Diving Symposium.* New Orleans, Louisiana, February 4-6, 1980.

March, N.F. Scuba for IPPB. *Proceedings International Diving Symposium.* New Orleans, Louisiana, February 4-6, 1980.

March, N.F. In-water CPR and emergency regulator resuscitation. *Proceedings 1980 North Pacific Chapter of the Undersea Medical Society Annual Meeting.* Avalon, Catalina, California, October 2-3, 1980.

March, N. F., and R. Matthews. Resusci-Annie goes to sea. *Journ. of Emergency Medical Services* 11:9 (1979).

March, N. F., R. C. Matthews, and J. B. West. New techniques in external cardiac compressions: aquatic CPR. *Proceedings NAUI IQ.* Houston, Texas, October 10-14, 1979.

March, N. F., and R. Matthews. Feasibility study of CPR in the water. *Journal of Undersea Biomedical Research* 7(2):141-148 (1980).

March, N. F., and R. Matthews. New techniques in external cardiac compressions; aquatic cardiopulmonary resuscitation. *Journal of the American Medical Association* 244:1229-1232 (1980).

Skin Diver Magazine, CPR all wet. (October, 1979 Medifacts)

Cooperating Organizations

American Medical Association
American National Red Cross (San Diego Chapter)
Elder Oxygen Company
Gould, Inc.
International Association of Dive Rescue Specialists
Laerdal Medical Corporation
P.A.D.I. International College, San Diego
San Diego City Lifeguard Service
Scripps Institution of Oceanography
SCUBAPRO Inc. - A Division of Johnsons Wax Associates
Undersea Medical Society
U.S. Coast Guard (Special Medical Operations Branch, Washington, D.C.)

Investigation of Population Genetic Structure in Abalones

UC Davis
R/NP-1-8B
1978-80

Dennis Hedgecock

Abalones (*Haliotis* spp) are currently receiving much attention because of their mariculture potential. Recent progress in controlling spawning has helped renew interest in hatchery-seeding programs. Unfortunately, this work has proceeded without basic information on the genetic structure of natural populations. Such knowledge can significantly affect selection of spawners, mating schemes, and release sites, as clearly seen in the case of salmonid fisheries and mariculture.

The ecology and demography of abalone populations suggest that genetic differences might arise among populations from different locations. The distribution of abalones is generally clumped, reflecting the location of suitable habitats and algae. Young abalones settle gregariously in patches of good habitat and are relatively sedentary throughout long adult lives (often more than ten years). Adult longevity and island-like distribution, therefore, provide ample opportunity for natural selection to cause genetic differences among populations in different locations. Dispersal of pelagic larvae is expected to counterbalance diversification of adult subpopulations, but the balance between local selection and migration might still allow subpopulations to become differentiated. If such differentiation did exist, hatchery programs might not only disturb the naturally adaptive genetic diversity, but also jeopardize their own success by transplanting genotypes to unsuitable environments.

Electrophoretic techniques were developed to analyze small pieces of mantle tissue from animals taken by a local commercial diver. This greatly reduced the cost of obtaining specimens, and the number of individuals finally studied was over four hundred. In all, seven populations of red abalones *Haliotis rufescens* and two of pink abalones (*H. corrugata*) were sampled in the Santa Barbara Channel Islands area.

Among the seven to ten gene-enzyme systems detectable in mantle tissue, two were found to be polymorphic in both species. Statistical comparisons of the frequencies of the electrophoretic variants showed no differences among localities at one gene, and a few slight differences at the other gene. In the absence of further data, it seems safe to conclude that population differences are not large enough to warrant great concern over the impact of hatchery releases on the genetics of the abalone resource.

Cooperating Organizations
Commercial Abalone Divers Association of Santa Barbara (John Colgate)

Dioxins--Historical Record of Fluxes in Lake Michigan Sediments

UC San Diego
R/NP-1-8C
1978-79

Edward D. Goldberg and John J. Griffin

The group of chemicals known as dioxins are among the most powerful mutagenic agents that can affect human health. The Environmental Protection Agency demands a zero discharge from United States chemical plants for these compounds. The Dow Chemical Company plant in Midland, Michigan, has measurable discharges, which are confirmed by dioxin levels in fish from the river into which the plant effluent is discharged. Dow scientists have apparently found that dioxins are produced in a variety of burning processes -- incineration, fossil-fuel combustion, internal combustion engines of automobiles, the charcoal grilling of foods, cigarette smoking, etc. They argue that dioxins have been produced by both natural and anthropogenic agencies. However, the important concern is whether natural processes produce dioxin fluxes similar to those of human facilities.

The goal of this project has been to compare the natural and anthropogenic inputs of dioxins to the Lake Michigan environment. The sediments of Lake Michigan are influenced by the highly industrial areas of Wisconsin, Michigan, and Illinois. By analyzing box cores, we set out to ascertain whether the natural fluxes of dioxins to the environment from forest and grass fires are comparable to the fluxes from chemical industry through the discharge of wastes and

from fossil fuel combustion.

Two box cores have been obtained from southern Lake Michigan, and their strata have been assigned ages by Pb-210 techniques. The lowest levels were deposited in about 1828. We have developed methods to indicate anthropogenic inputs to the sediments through their elemental carbon contents and flyash, both magnetic and nonmagnetic. We have come up with a generalization about human high-temperature inputs: they are spherical in form, as opposed to the nonspherical or angular inputs from natural burning processes such as forest fires.

Further, we have analyzed the following metals: lead, tin, cadmium, zinc, cobalt, manganese, nickel, chromium, aluminum, copper, iron, and vanadium. Most of these metals as well as elemental carbon (soot), show a monotonous increase in concentration from 1828 to the early 1960s, when there is a marked falloff. The metals and the soot are probably injected into the atmosphere from industrial activity. We suspect that the recent decrease in these concentrations may be due to improved flyash collection from power plants and industrial organizations.

One of the few laboratories in the world capable of measuring dioxin levels in the environment is that of Professor Otto Hutzinger at the University of Amsterdam. We have taken a frozen slice of one of the cores to him for analysis.

Publications

Griffin, J. J., and E. D. Goldberg. Morphologies and origin of elemental carbon in the environment. *Science* 206:563-565 (1979).

Cooperating Organizations

Argonne National Laboratory, Radiological and Environmental Research Division

Development of a Prototype Course in Marine Policy

UC San Diego
R/NP-1-8D
1979

Jens C. Sorensen

In the spring quarter of 1979, the Department of Political Science at UC San Diego offered an introductory course in marine policy for advanced undergraduates and graduate students. Class members were highly motivated students who represented a broad range of backgrounds.

Our first objective was to develop and test an alternative approach for teaching marine policy. A similar class had been taught at UCSD before, but we wished to reorganize it and to draw upon the experience of other instructors of marine policy in universities around the country.

A review of course syllabi from other universities indicated that instruction is almost always organized according to the various sectors of ocean activity, such as national defense, transportation, fishing. This sector-by-sector organization of course materials poses a number of educational problems. Students are apt to be confused by a vast spectrum of policy that appears to have few points in common except salt water. Also, a sector-by-sector approach usually does not give the factual and theoretical framework a student needs to analyze marine policy. We therefore divided our marine policy course into two components:

1. A theoretical and factual framework, including:
   - Distribution of and access to coastal and marine resources
   - Property rights and common property resources
   - Limits of scientific analysis (modeling cause-and-effect relations)
   - Social justice, equity questions, and the new international economic order
   - Institutional arrangements
2. Case studies, including:
   - Vessel source oil pollution
   - The California Current Anchovy Resource: California-Mexico conflicts and domestic conflicts between the recreational and commercial interests
   - Manganese nodules and the risk of deep sea mining
   - Siting power plants on the California coast (San Onofre Nuclear Power Plant)
   - Reasonableness of California's ocean discharge standards
   - Ocean research and jurisdictional claims of ocean states
   - The tuna-porpoise controversy

Our second objective was to determine the extent to which university students in a seminar

context can assist in developing issue papers that will be useful to public policy makers. Seven issue papers were produced by the students working as multidisciplinary teams. One issue paper on vessel oil source pollution is being considered as an article by the *Journal of Ocean Development and International Law.* The annual Law of the Seas issue of the *University of San Diego Law Review* included an article that drew largely from a paper describing national claims and the freedom of oceanic research. The paper on anchovy management was used as a background paper for the Commission of the Californias' research on United States -Mexican marine resources management.

Publications

Barton, J. The impact of UNCLOS proposed treaty provisions on marine scientific research. *University of San Diego Law Review* (Special Law of the Seas Issue). Vol. 18 (1980).

Meese, S. When jurisdictional interests collide: international domestic and state efforts to prevent vessel source oil pollution. Accepted for publication by *Ocean Development and International Law: the Journal of Marine Affairs.*

Sorensen, J. C. Coastal and marine policy analysis: combining education and program evaluation. *The Role of Policy Analysis in the Education of Planners,* paper presented to the MIT-sponsored Symposium on Policy Analysis Education, Oct. 11-12, 1979 (1980).

Cooperating Organizations

Commission of the Californias
University of San Diego Law School

Coastal Wetlands Management: Review of and Recommendations about Local Plans

UC Santa Barbara
R/NP-1-8E
1978-79

Christopher P. Onuf

Management of the natural resources of coastal wetlands requires introducing the best available scientific knowledge and opinion into the planning process. This project was conceived to foster essential dialogue between wetlands scientists and government planners--groups who have lacked understanding of each other's needs, expectations, and capabilities. A request from the California Coastal Commission to review and evaluate the scientific validity of two existing planning documents offered an excellent opportunity to base discussion on explicit case studies.

Two local plans, the Agua Hedionda Specific Plan and the Sensitive Habitat Report on Goleta Slough, were compared and critiqued as prototypes for other plans. Current Sea Grant projects on coastal wetlands management provided scientific background. The adequacy and appropriateness of the plans' provisions for protecting coastal resources were evaluated. A standard method of biological analysis was recommended for use in other plans.

The evaluations were sent to appropriate scientists and agency representatives, who were invited to a workshop in Santa Barbara in May of 1979. The workshop participants' wide experience and broad perspective further refined our recommendations.

Proceedings of the workshop, setting forth development guidelines and criteria for the protection of coastal wetland resources, are in the process of being published.

Publications

Background papers prepared for the workshop:

Onuf, C. P. Protection of coastal wetland resources as provided by the *Agua Hedionda Specific Plan* - a critique. 26 pp, 1979.

Onuf, C. P. The city of Santa Barbara's environmentally sensitive habitat draft report on the Goleta Slough: a review of provisions for the protection of natural resources. 16 pp, 1979.

Onuf, C. P. Guidelines for the protection of the natural resources of California's coastal wetlands. Proceedings of a workshop on coastal wetlands management held at University of California, Santa Barbara, May 24-26, 1979.

Cooperating Organizations

California Coastal Commission

Methods of Increasing Diver Effectiveness through CO_2 Absorbers and Decompression Computers

UC Berkeley
R/NP-1-8F
1978-79

C.D. Mote, Jr.

Two of the major restrictions on a diver's bottom time are the time spent decompressing upon return to the surface and the size and weight of the required CO_2 absorbers.

Existing absorbers tend to be large and heavy. A quantitative understanding of the CO_2 absorption process would permit the design of more efficient absorbers. This project has designed and built an experimental apparatus to study the effects of inlet velocity, helium/oxygen mixture, and initial CO_2 concentration on the absorption effectiveness of a bed of barium hydroxide granules.

We also developed a microprocessor-based decompression computer for use by divers. Current decompression practice using staged ascent rather than a continuous ascent results in inefficient use of time and gas volume. The continuous ascent approach is based on the predicted partial pressure of the absorbed diluent gas in the tissues, and frequently results in shorter decompression times. A microprocessor was programmed to calculate the predicted tissue partial pressures in real time and to display the minimum safe ascent depth to the diver through a wrist-mounted light indicator.

The tissue partial pressure computer program is based on a mathematical model derived for the U.S. Navy's standard air decompression table. This model predicts tissue partial pressure in seven body tissues as a function of depth and time at depth. The computer then compares these values to the maximum allowable for each tissue and decompression stop.

A breadboard of an Intel 8085 microcomputer was built and tested. The output display and expansion memory circuitry have been designed, built, and interfaced to the microcomputer. The input pressure transducer and A/D converter circuits have been designed, built, and interfaced to the microcomputer. Seven software subroutines for the microcomputer were written and tested.

Publications

Fryberger, T. and Mote, C.D., Jr. Increasing diver effectiveness with carbon dioxide absorbers and microprocessor decompression computers. Department of Mechanical Engineering Report, University of California, Berkeley, February 1980.

Wetlands Restoration Option Study--Ballona Wetlands

UC Los Angeles
R/NP-1-8G
1978-79

John R. Clark

A major stumbling block for many Local Coastal Programs in completing their planning has been interpreting and implementing the ecological policies of the 1976 Coastal Act, particularly those concerned with wetlands and estuaries. This project was designed to assist local governments by sharing scientific information and expertise with planners.

The wetlands lying within the "Ballona Gap" of coastal Los Angeles County, along with their adjacent lagoons and shallows, originally (in the early 1800s) covered 2,100 or more acres. While much of this has been irretrievably converted to other uses, about 515 acres are either actual wetlands or are vacant land that once was and again could be wetlands if a large commitment were made to restoration. Acreages are roughly as follows: 120 acres of existing vigorous wetlands, 180 acres of wetlands that are easily restorable to vigor, and 215 acres of wetlands more difficult to restore.

The wetlands as a whole are suffering from deprivation of tidal flushing. The problem is caused by dikes, berms, fills, and roads that were built many years ago before the high values of wetlands were appreciated. It appears that simple grading and reshaping of the wetland surface along with improving water flows and providing edge-zone buffers would restore much of the Ballona Wetlands west of Lincoln Boulevard to a nearly natural level of function. The wetlands are, even in their altered state, performing typically valuable natural salt marsh functions.

The question this study grapples with is how these wetlands can be preserved in a long-term

functioning condition in view of the press of urban development in Los Angeles County. We set out to determine options for restoring, developing, and preserving the wetlands and to advise the Los Angeles County Department of Regional Planning, the California Coastal Commission, and other interested parties.

The County of Los Angeles has approved a General Plan and is preparing the Local Coastal Plan (due January 1981). Each of these must address the subject of wetlands conservation. However, the title holder to the Ballona Wetlands, the Summa Corporation, has released a concept plan (April, 1979) that would preempt about 300 acres of functional wetlands in the Ballona area for urban development. Under federal and state laws and programs concerned with wetlands conservation, as well as county ecological protection policies, the use of wetlands for such general urban development would normally be disallowed. Thus, planning for conservation and for development are on a collision course.

Our study has consolidated and interpreted existing information to the following plan elements:

1. Constraints on use of the tract because of recognized limitations (air and water quality, highway loading, public services shortfall, local zoning, height/bulk restrictions, geologic conditions, etc.)
2. Identification of wetland boundaries (existing and former)
3. Habitat and other needs of biota and observed impacts (diversity, breeding/feeding/resting, endangered species, nurseries)
4. Needs for restoration, enhancement, buffers, resource protection zones, and other related considerations
5. Optimal designs for restoration of the presently degraded wetlands (nearly all) under marina or general development options
6. State/federal policies, regulations, and requirements affecting use and protection of the area
7. Economic and environmental impacts of various use mixes
8. Determination of probable public and private (landowner) rights in the existing and restorable altered wetland and waters
9. Opportunities in the tract to meet priority public needs (housing, boating, nature study, jobs).

This study has convinced us that the conflicts surrounding the Ballona Wetlands could be resolved with a redesign of the proposed development, and we have recommended negotiation to this end.

Publications

Clark, J. R. Options for Ballona: problems of conserving a Los Angeles urban wetland, draft.

Recreation Transportation Analysis for Coastal Planners: A Technical Report on the Methods Used in California

UC Berkeley
R/NP-1-8H
1979

Adib K. Kanafani and James E. Burke

How to resolve the transportation conflicts between recreation development and residential, commercial, and industrial development in the coastal zone is a continuing problem for planners. This problem is aggravated by increasing attendance at coastal recreation facilities and the uncertain travel behavior caused by restricted supplies and increased costs of gasoline.

The objective of this project was to write a report on coastal access, emphasizing recreation transportation, that would be useful to planners developing Local Coastal Programs for California governments.

Coastal access studies undertaken in California were reviewed. In addition, public and private transportation planners were interviewed to determine the status of coastal access planning in California. This research was carried out with the close cooperation of the California Coastal Commission.

The report was sent to reviewers throughout the state before its publication.

Publications

Burke, J. E. Coastal access analysis in California: an assessment of recreation transportation analysis in coastal planning. Institute of Transportation Studies, University of California, Berkeley, 1979.

Cooperating Organizations

California Coastal Commission

The Politics and Policy Implications of Deep Seabed Mining: U.S. Options

UC Santa Barbara
R/NP-1-81
1979-80

Dean E. Mann and Kurt M. Shusterich

This report summarizes the research findings from four major areas of the project. The first is an analysis of the ocean mining industry. This industry was found to have been successful in influencing United States ocean mining policy at both the legislative level and at UNCLOS III. It has failed, however, in its efforts to obtain complete "grandfather rights" protection in the deep seabed mining legislation that was signed into law by President Carter on June 28, 1980.

Of the five joint ventures involved in ocean mining, only two, basically American, consortia have been successful in maintaining their research and development programs. Ocean Mining Associates (OMA), for example, plans to start producing 1.8 million tons of nodules each year from the seabed by 1989. As of 1980, OMA had spent $70 million on research and development with plans for another $100 million. Ocean Minerals Inc. has also been successful in maintaining its research and development program. This is mainly due to the large amounts of oil money available through one of the members of the consortium.

All of the ocean mining consortia agree that an LOS treaty could kill off most major commercial projects. The American and German companies have had some success in securing ocean mining legislation that provides them enough legal protection to go ahead with research for full-scale operations. At present, however, the costs associated with nodule mining and processing are too high and the rewards too meager for several consortia to maintain research and development levels. Mining executives say they will need a return on their investment of 20-30% to compensate for the risks involved. The likely rate for first-generation operations, however, appears to be only about 8-10%. Despite industry's claim that it has held back on full-scale operations because of legal and political uncertainties, research has shown that it is primarily because of the poor metals market and low returns on investment that they have not progressed further.

Consequently, the remaining companies involved have either government financial and research assistance--in the case of German, French, and Japanese groups--or they have substantial quantities of oil money backing them. This fact raises important questions beyond the scope of deep seabed mining alone. Specifically, should the United States assist American corporate resource interests, and if so, in what ways? For instance, should there be more or less of a government role in American ventures that are competing with other government-aided foreign companies in the international marketplace--especially for minerals? If American corporate interests succeed in securing a sizable share of resource markets, then there is no need for special government consideration. If, on the other hand, they find themselves unable to do so, then government assistance in the form of special loans or less governmental restriction may be in order.

A second area of the project is concerned with the political and institutional actions of the U.S. government regarding international ocean resource problems and policies. This section includes a history of the deep seabed mining legislation that had been in Congress since 1971 before it became law in 1980. In general, it was found that different departments and agencies within the administration have different goals and objectives for U.S. ocean policy. This situation accounts for some of the concessions made by the U.S. delegation at the Law of the Sea negotiations. A major difficulty for American representatives to the LOS negotiations was that the ocean mining industry often gave misleading, or failed to provide, information and data to State Department negotiators at UNCLOS III. This resulted in a pro-industry stance at the negotiations up to 1976. Industry's lobbying emphasis on the need to secure varied supply sources of valuable minerals by the turn of the century has met with a good deal of support throughout the government.

The research has pointed to several international and domestic factors that have influenced U.S. ocean mining policy over the past two decades. Internationally, there has been (1) an increase in the number of new nations; (2) an increase in the number of multilateral conferences for dealing with basic economic and resource issues--and an increase in the politicization of those conferences; (3) a decrease in the economic power of the United States vis-à-vis Western Europe and Japan; and (4) a decrease in the technology monopoly held by the United States. Domestic factors include (1)

the major role of personalities in early ocean mining legislation and in the official American UNCLOS III negotiating stance; (2) the generally conservative nature of the State Department (as the key American negotiating apparatus at UNCLOS III); and (3) increase in the number of technocrats involved in several bureaus associated with ocean policy formation.

A third area of the project deals with the relationship between the efforts of the Group of 77 to press for a New International Economic Order at UNCLOS III. We found that ideology and basic philosophical differences have long been a major problem in resolving ocean resource use issues at the LOS sessions. Efforts by the Group of 77 to have the International Seabed Authority (ISBA) set an example for a new international order account for the delays in reaching agreement on the deep seabed mining aspects of the treaty. It is likely that even if the U.S. delegation signs the present draft treaty, the Senate will not ratify it. This situation gives added relevance to the passage of unilateral legislation.

While there have been splits within the Third World coalition between coastal, geographically disadvantaged, and noncoastal states, the Group of 77 has held together throughout the negotiations. The LOS conference has taught the Group of 77 a great deal in a short period of time concerning its economic and political relationships with the industrially advanced states. This point is well illustrated by the increasing pressure put on the northern states to share technology for seabed mining and for access to the resources of Antarctica and outer space.

The fourth area of the project deals with possible precedents for management regimes for Antarctica and outer space. We have found growing pressure from the Third World for a sharing of technology and of the benefits from the exploitation of international resource commons. Many of the arguments used by the Group of 77 for access to these areas are based on the common heritage concept that is at the ideological heart of the International Seabed Authority. The Moon Treaty, for example, bears remarkable similarities to philosophic underpinnings of the common heritage concept found in the Law of the Sea draft treaty.

In general, our findings have led to the following conclusions: first, resource access and ownership is taking on greater political and economic significance in international relations. This is especially so since the 1973 OPEC embargo of oil to the West. Technology alone does not carry the same economic weight it did for the United States following the Second World War. Second, because of the importance of access to resources, many industrially advanced nations are working very closely with their resource-related industries. In ocean mining this has resulted in more nationalist-minded enterprises in and a breaking up of the international nature of some of the consortia. Third, because of this, the U.S. government may have to work more closely with, and be much more supportive of new, high-technology, infant resource industries such as seabed mining if the nation is to secure access to resources and maintain its technological advantages in the coming decades when resources become more scarce and strategically critical.

Cooperating Organizations
Charles River Associates
House Merchant Marine and Fisheries Committee
Massachusetts Institute of Technology
United States Departments of Commerce, Interior, and State
University of Southern California

Procurement of Wildstock Sturgeon

UC Davis
R/NP-1-8J
1979

Wallis H. Clark, Jr. and Serge I. Doroshov

An important and widespread food source, sturgeon are highly vulnerable to human impact because of their specific requirements during the reproductive cycle. Ineffective regulation of United States commercial fisheries and damming of spawning rivers have dramatically reduced U.S. sturgeon populations. The only means of protecting sturgeon species from extinction are artificial reproduction and stock replenishment. Artificial recruitment has a high potential for conserving the species and enhancing commercial and sport sturgeon fisheries in many areas.

In this project we have worked to develop technology necessary for a prototype sturgeon hatchery for two native species, the white sturgeon (*Acipenser transmontanus*) and the green sturgeon (*A. medirostris*). Immediate objectives were the collection, transportation, acclimation, and holding of sturgeon broodstock for hatchery

operation. We made preliminary assessment of gonadogenesis and induced ovulation and spermiation for artificial spawning.

Broodfish (35 to 65 lb individual weight) were caught in the San Francisco Bay, Sacramento River, and Klamath River, and transported to the UC Davis aquaculture facilities in a 400-gallon aerated transportation tank. Optimal acclimation from seawater to freshwater (for fish caught in the Bay Area) was defined as an abrupt decrease in salinity from 32 to 20 ppt, followed by gradual replacement with freshwater during the next 12 hours.

Transported fish were held (without any mortality or disease problems) in a 400-gallon, freshwater tank at 16°C, with a flow rate of 4 GPM and terramycin treatments twice a week. Spermiation was induced in males with a single injection of 500-700 IU of HCG/kg of body-weight. Ovulation was promoted in one female with combined injections of 1000 IU of HCG and 30 mg of acetone-dried carp pituitaries. Selected fish were sacrificed, and their morphometry, gonadosomatic indexes, gamete development, and structure were investigated. Data obtained will be used as guidelines for wild broodstock procurement and artificial spawning of sturgeon in the UC Davis sturgeon hatchery study during 1980.

Publications

McGuire, A. B. The big fish--restoring California's sturgeon population. *California Agriculture* 33(10):4-6 (1979).

Cooperating Organizations

California Department of Fish and Game
Yurok Indian Tribe
Sport fishermen's organizations in the Bay Area

Feasibility Study to Assess the Development of an Applied Marine Research Directory

UC San Diego/UC Santa Cruz
R/NP-1-8K
1978-79

Jens C. Sorensen, R. Andrew Cameron, and John B. Gage

In California there are many institutions and individuals conducting marine and coastal research. According to a recently compiled directory of California marine science programs, there are eighteen private and twenty-one public institutions of higher education with marine education programs. Yet it is difficult for those who could benefit from knowledge of a particular research project to be aware of its existence. For this reason, the development of a computerized directory of applied research has been given high priority in studies on improving state-university relations.

The directory could help the Sea Grant College Program fulfill its responsibility as liaison between the University of California and state government on matters of ocean and coastal resources management. The directory should also assist research funding organizations and university researchers and administrators in setting program priorities and identifying future projects.

This feasibility study had four interrelated objectives.

1. To assess the possibility of accumulating and managing a large data base that can be used to identify experts and applied research in the field of marine resources
2. To assemble a pilot data base consisting of (a) fisheries research conducted at all California institutions of higher education, and (b) all marine research conducted on one campus (Berkeley)
3. To test the capabilities of the system with appropriate users
4. To determine and develop interconnections between an applied research directory and other information operations such as the California Environmental Data Center, data bases of published research, and the Smithsonian's Scientific Information Exchange Program.

We have acquired and encoded two hundred records from the Smithsonian Scientific Information Exchange. A search of State University documents and the National Marine Fisheries Directory has yielded 125 records; these too have been encoded. We have obtained the tape listing all the University of California's nonconfidential research projects: fisheries research on all UC campuses and the applied marine research projects at the Berkeley campus have been encoded into the data base.

Our study indicates that a complete data base listing all marine research conducted by institutions of higher education and governmental agencies in California could be prepared in a cost-effective manner.

Cooperating Organizations

University of California systemwide administration, Office of Contracts and Grants

Chancellor's Office, California State University and College System

Demographic Analysis of Porpoise Populations Subject to Time-Varying Tuna-Net Mortality

UC San Diego
R/F-56
1979-80

Daniel Goodman and Jay Barlow

Natural mortality rates are notoriously hard to measure, but if known, they would be of great utility in the management of harvested populations. Stable population theory can be used, when appropriate, to estimate mortality rates from age distributions. Unfortunately, the application of this theory to harvested populations is often compromised by recent changes in harvest rates.

Working with porpoise involved in the yellowfin tuna fishery, we have been developing the methodology that will allow us to circumvent the restrictive requirements of stable age distribution in estimating mortality rates. For these porpoise, we know that the mortality incidental to the tuna fishery has decreased dramatically in the last ten years. We consider mortality as consisting of two components: an unchanging natural mortality and a time-varying harvest mortality. This allows us to estimate the natural mortality component, provided the current age distribution and the time history of harvests are known.

Data for this study are being provided by researchers at the Southwest Fisheries Center (SWFC), NMFS. One aspect of our work has been scrutinizing these data to determine whether biases or other factors might complicate our analyses. We have identified three potential problem areas. First, the representation of very young porpoise (less than six months) in the kill samples tends to vary over a two-fold range, depending on the total number of porpoise killed in a given net set. This would bias the age distribution calculated from the sample of killed porpoise. By using only those samples taken from sets with large total mortalities, we believe that these bias problems can be resolved.

A second complication was the discovery of strong patterns of reproductive seasonality in several of the dolphin stocks. Although the northern offshore spotted dolphins *(Stenella attenuata)* show very little seasonality in their reproductive cycle, the eastern spinner dolphins (*S. longirostris*) are strongly seasonal. The strongest seasonal pattern of all was found in the southern offshore spotted dolphin, a fact that was cited as contributing evidence for separating this stock as a management unit from the northern offshore spotted dolphin. Reproductive seasonality means that adjustments to the age distributions may be necessary to correct for the time of sampling. Finally, we have determined that the age distributions taken from current age estimates (figure 1) are either

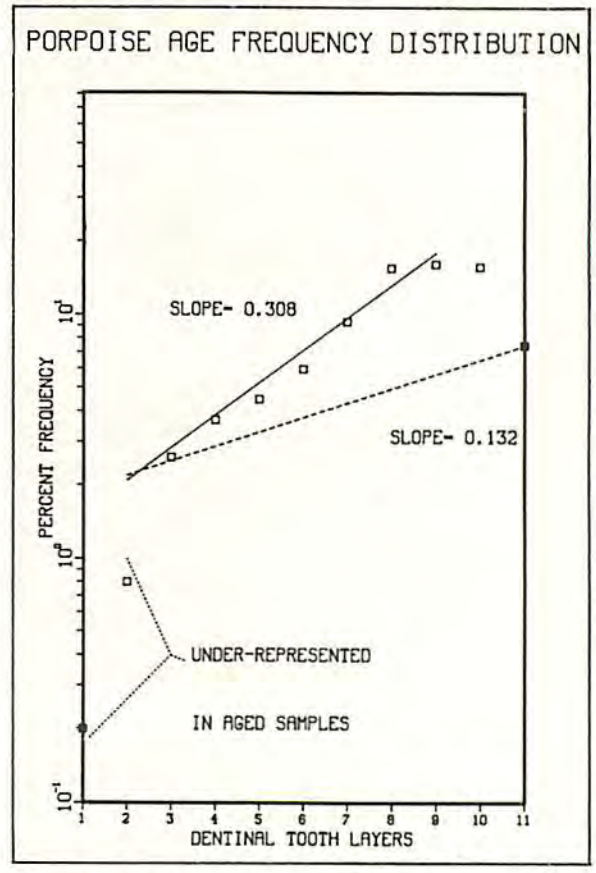

Figure 1. Age frequency distribution for female spotted porpoise using tooth layer counts as a relative measure of age and using percent frequency plotted on a logrithmic scale. Taken from Goodman (1979).

incorrect or else they imply a dramatic rate of population decline (>20% annually). New methods of aging dolphin teeth have been developed by researchers at the SWFC and are currently being used to obtain revised age esti-

mates.

The other principal aspect of our work has been the development of models for estimating natural mortality rates. Lacking, for the moment, a believable age distribution for the porpoise, we have applied our models to other examples where reliable data are available: the harp seal of the northwestern Atlantic and the Kaibab deer of north-central Arizona. Using the deer data we compared two common methods of estimating mortality rates from age distributions with a third, which we propose to use on this project. The logarithmically transformed linear regression and the Chapman-Robson method gave ostensibly the same result as the method we are proposing to use--a non-linear least square parameter fit (table 1). Like the Chapman-Robson method, the non-linear regression provides a variance for the survivorship estimate. Like the logarithmic regression models, the non-linear regression is adaptable to cases where mortality changes with age. Unlike either of the other methods, the non-linear regression is also adaptable to our needs. That is, it can be applied to cases where harvest mortality has changed over time.

Table 1
Survival Rates for Female Kaibab Deer as Estimated From Harvest Age Distributions by Three Methods

	Annual Survival Rate	S.E.
Log-linear regression	0.659	
Chapman-Robson method	0.680	0.0075
Non-linear regression	0.679	0.0080

Publications

Barlow, J. Reproductive seasonality in pelagic dolphins of the eastern tropical Pacific. NMFS Status of the Porpoise Workshop Document No. 26. (1979).

Goodman, D. Interpreting spotted porpoise age distributions. NMFS Status of the Porpoise Workshop Document No. 51. (1979).

Goodman, D. On the interpretation of transient age structure. IUCN and WWF Workshop on the Biology and Management of Northwest Atlantic Harp Seals, working paper #7 (1979).

Goodman, D. Calculation of vital rates from age distributions. Worldwide Furbearer Conference, Frostberg, Maryland, 1980.

Powers, J.E. and J. Barlow. Biases in the tuna-net sampling of dolphins in the eastern tropical Pacific. NMFS Status of the Porpoise Workshop Document No. 31. (1979).

Cooperating Organizations

National Marine Fisheries Service, Southwest Fisheries Center

An Economic Analysis of the Gains from Joint Management of Transboundary Fishery Stocks

UC Davis
R/NP-1-9A
1979-80

Warren E. Johnston and Richard E. Howitt

Our goal has been to conceptualize a framework to empirically assess the economic consequences of alternative management policies for transboundary fish stocks. We have sought to identify potential gainers and losers from various management schemes, and to analyze the effects of institutional structures and trade barriers on harvesting and marketing.

We have progressed toward our objectives in two ways. First, the conceptual framework needed to determine the benefits of alternative management schemes for transboundary stocks is in the final stages of formulation. In particular, we have specified an annual econometric model describing the factors influencing a country's (or industry's) decision to market or harvest a given species of fish. We are now revising this annual model to incorporate seasonal fluctuations in harvesting patterns and consumer demand. The revised model will be a quarterly model, estimating behaviors and responses for smaller time segments.

Secondly, in order to empirically test the econometric portion of the model, and to evaluate an overall framework for assessing benefits of alternative management schemes to the United States and Canada, we have been collecting data on the North Pacific halibut industry from secondary sources in both countries. We have also interviewed fishermen and industry representatives and have been in touch with the International Pacific Halibut Commission. We have obtained preliminary results for an annual model; these results strongly suggest the need to account for seasonality at the ex-vessel and marketing levels.

During the 1980-81 project year, we are estimating quarterly econometric models for the U.S. and Canada, as well as a quarterly model for the combined U.S.-Canada market, which accounts for both spatial (trade) and time dimensions. These represent major econometric tasks.

The biological system that describes the growth and recruitment relationships of the particular species and simulates the effect of alternative amounts of fishing on future yields also needs to be specified consistently with the

economic models. The biological model for the Pacific halibut fishery is available from the NMFS, but must be updated and revised to conform to our specifications of variables. Fishery scientists at UC Davis and in Seattle are assisting with this task.

Another aspect of this model is the identification of an objective function for the optimization required to assess the overall effects of alternative transboundary fishery stock management scenarios. For example, one objective function might be to maximize the economic surpluses at the harvesting, processing, and marketing levels for both countries. The effects of different policies in the respective countries can then be assessed, using quarterly econometric and biological models.

A perspective on the interactions of the segments described above can be obtained from the following overly simplified description. The reduced forms of the econometric model are derived and transformed into a set of difference equations. The biological system can also be expressed in difference equation form. Given initial conditions and time paths for the exogenous variables, the entire system is then to be simulated over the planning horizon. Simulation and control techniques are needed to assess the impacts of alternative management and marketing schemes.

As we conclude this project, we will estimate the effects of alternative strategies for managing the North Pacific halibut, an important transboundary fishery stock in the western U.S. The generalized research methodology developed in the project should be suitable for application to other transboundary fisheries.

Publications

Capalbo, S.M. Gains from international management of a renewable resource: a case study of the North Pacific halibut. Ph.D. field research essay, Department of Agricultural Economics, University of California, Davis, 1979.

Cooperating Organizations

Government of Canada, Department of Fisheries and Oceans
Icicle Seafoods Inc., Seattle, Washington, and Hormer, Alaska
International Pacific Halibut Commission
NMFS, Northwest and Alaska Fisheries Center
University of Alaska, Sea Grant Program

Feasibility of Mechanical Skinning of Blue Shark

UC Davis/CSU, Long Beach
R/NP-1-9B
1979-80

R. Paul Singh, Barbara A. Katz, Roger E. Garrett, and Daniel E. Brown

Blue shark (*Prionace glauca*) is found in abundance in the waters off southern California, but is not widely used for food, and is considered a pest by most commercial and sport fishermen. A wider market for blue shark products is being sought: for example, if removed in one piece, the skin can be used for making leather.

The Japanese market for blue shark products was investigated. Four Japanese companies were interested in marketing the hides; five companies were interested in marketing the meat; and nine were interested in marketing the fins.

Ocean Leather Corporation, of Newark, New Jersey, has been converting shark skins into leather for shoes and other prestige leather goods since 1972. Their required hide shape is pictured in figure 1. They require hides at least 1.2 m (40 in) long and free from sour spots (decomposition), butcher cuts (knife cuts into the hide from the skinning process), fighting scars, and burnt spots (prolonged exposure to sun before processing). To insure top-quality hides they insist the hide be removed as soon as possible after the shark is caught. The hides

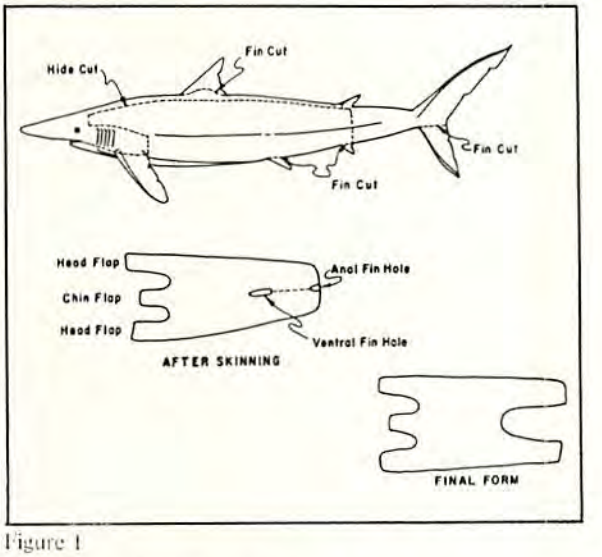

Figure 1

cannot be frozen or exposed to fresh water, and must be fleshed (excess meat removed), salted or pickled to preserve them, and packed for shipment.

To successfully provide blue shark products for these markets and to be compatible with existing fishing techniques, it is necessary that

the sharks be processed immediately after being caught. The major goal of this project was to determine if it is technically feasible to skin blue sharks with a mechanical device on board the fishing vessel. This device should yield (1) a high-quality meat product that is easy to handle in the processing plant and (2) a hide suitable for use in the leather industry.

We set about to determine the physical properties of blue shark that are important to the design and development of a skinning machine.

Three frozen blue sharks were donated by the commercial fishing vessel *JJ* for use in these tests. Head, fins, viscera, and tails had been removed prior to shipment. Overall length of these sharks ranged from 1.2 - 1.8 m (4-6 ft).

The carcasses were thawed at room temperature, and samples of skin or flesh were cut at or near the three sections indicated in figure 2.

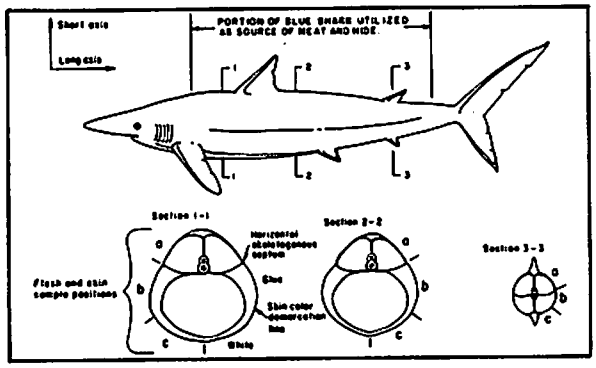

Figure 2

Samples were taken from the carcasses up to 15 cm anterior and posterior of the indicated sections, numbered 1, 2, and 3. The sample positions at these sections were further differentiated into a, b, and c. Sample position a denotes those skin and flesh samples on the dorsal side of the horizontal skeletogenous septum. Position b samples were taken from the ventral side of the horizontal skeletogenous septum and dorsal with respect to the skin color demarkation line. Position c samples consist of the white skin covering the ventral surface of the shark and the flesh it covers. Because of the difficulties caused by the horizontal skeletogenous septum, samples were taken from either side of it.

Each shark was split longitudinally with the shark's right side used for experiments parallel to the long axis, and the left side used for experiments parallel to the short axis (figure 2).

Tests to determine tensile strength and breaking elongation (ultimate elongation) of flesh and skin, and the work required to separate the skin from the flesh (adhesion work) were performed on an Instron Universal Testing Instrument (Model TM-M, Instron Engineering Corp., 2500 Washington Street, Canton, MA 02021). A Warner-Bratzler type shear press was used to determine the shear strength and shear work of flesh and skin. The shear blade was mounted in the crosshead of the Instron Testing Instrument. Adhesive work was determined by performing a modified T-peel test (ASTM D1876-61T).

Findings

1. Tensile strength of blue shark skin ranged from 3-13 MPa (440-1900 psi) and was two orders of magnitude greater than that of the flesh.
2. Shear strength of the skin was approximately equal to the tensile strength of the skin and ranged from 1.5 - 12.5 MPa (220-1800 psi). Shear strength of the skin was ten times greater than that of the flesh.
3. Shear work for blue shark skin ranged from 0.5 - 6.0 J (0.4-4.4 ft-lb) and was three times greater than that for the flesh.
4. The adhesive work required to peel the skin from the flesh of blue shark ranged from 0.1 - 3.2 kJ/m^2 (2.1 - 67.0 x 10^5 ft-lb/in^2). Less work was required to peel the shark parallel with its short axis.

Conclusions and Proposed Design of Skinning Machine

Not only is less adhesive work required to skin blue shark along the short axis; we also observed that the amount of meat remaining on the skin after the peel tests for the short axis was less than that for the long axis. Also, there was less meat remaining after the peel tests than when the sharks are manually skinned with a knife. If the skins are pulled from the sharks parallel to the short axis, it should be easier to flesh the hide once it is removed. These observations, plus the requirement by shark hide processors that no butcher cuts be made in the hide, make it advantageous to peel the skin from the shark rather than cut it away.

We envision a shipboard machine that would restrain the shark by means of a row of pneumatic or hydraulically driven gaffs mounted on a rigid beam. These would penetrate the dorsal surface of the shark, after removal of the dorsal fin. The cartilaginous spine and skull would be easily penetrated, thus killing the shark and reducing the nervous activity and movements that would interfere with the skinning process

and lower hide quality. Although the hide has been ruptured on the dorsal side, the form of the hide desired is still intact. The caudal and pectoral fins could then be removed and saved. The tail is then severed and the shark is bled.

A knife similar to the Wyoming Knife Corporation's Field Dressing Knife could be mechanically operated to follow the row of restraining spikes along the dorsal ridge of the shark to start the skinning process. This hide cut (figure 1) is made on the left- and right-hand sides of the dorsal ridge as close to its apex as possible. Because of the toughness of the hide, replaceable or disposable blades would be required.

Skin grippers of the type commercially used to manually remove strips of skin from dogfish sharks could be modified to grip the shark skin at the incisions along the dorsal ridge described above. Cables attached to these grippers could then mechanically pull the skin away from the flesh, around to the ventral side, and off the carcass. The hide could then be fleshed and trimmed to the form of figure 1. The carcass would then be gutted and put in cold storage.

However, the horizontal skeletogenous septum (figure 2) may have to be severed from the inside of the skin. The adhesive work required at its point of attachment to the skin was found to be two to three times that at other points on the body. The shear work required to sever it is approximately equal to that for the skin on the dorsal surface. Perhaps the knife that cuts through the skin at the dorsal surface could be reinserted to make the cut along the horizontal skeletogenous septum.

Publications

Brown, D. E., R. Paul Singh, R. E. Garrett, and Barbara Katz. Feasibility of mechanical skinning of blue shark. Final Report to the California Sea Grant College Program, May 1, 1980.

Cooperating Organization Fishing vessel *JJ* (John Christen and Jane Meyer)

Regulation of the Production of Dormant Cysts by the Brine Shrimp *Artemia salina*

UC Davis
R/A-41
1979-80

John H. Crowe and Lois M. Crowe

I. Survival of Freezing by Cysts of *Artemia*: Effects of Variable Water Content

The cysts of *Artemia* may be reduced to nearly undetectable water contents without killing them (Clegg, 1978). The dry cysts serve as a convenient food for young aquaculture organisms, for when the cysts are placed in water they rapidly rehydrate, resume metabolism and development, and hatch into free-swimming nauplii.

Because cysts are commonly stored at low temperatures, we investigated how water content affects the cysts' survival of freezing. In addition, we have provided evidence concerning the status of water in the dry cysts.

Materials and Methods

Cysts were decapsulated according to Sorgeloos et al. (1977) and vacuum dried to 10^{-5} Torr. Water contents of the dry cysts were adjusted by immersion in water for various intervals, after which the water was removed by suction and the cysts blotted. Water content was determined gravimetrically. To determine the effects of water content on survival of freezing, we placed the cysts in liquid nitrogen for 15 min, rapidly thawed them, and then placed them on 5% agar prepared in seawater. Survival was recorded after 48 hrs.

Ice content of frozen cysts was determined by thermal analysis. We packed the cysts in plastic capsules around a copper-constantan thermocouple to record thermal events during cooling, and then cooled the decapsulated cysts in an ethylene glycol bath to -24°C. In addition, frozen cysts were subjected to calorimetric analysis, as described by Levitt (1980). The calorimeter used for this purpose consisted of a 150 ml Dewar flask provided with a copper-constantan thermocouple. Amplification of the signal from this thermocouple permitted detection of as little as 3 mg ice.

To assess damage from freezing, leakage of conductive components from previously frozen cysts was measured with a Markson conductivity cell, as described by Levitt (1980).

Results and Discussion

Viability following freezing. Unfrozen cysts showed 80-85% hatchability 48 hours after having been placed on seawater agar. When the water content of frozen cysts was low (<0.6 g H_2O/g dry wgt), the hatchability was not significantly different from that of the controls (figure 1). However, when water content exceeded about 0.6 g H_2O/g dry wgt, hatchabil-

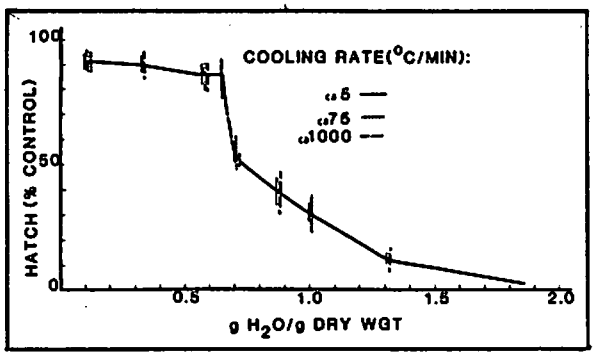

Figure 1. Hatching of cysts following freezing at different water contents and at the indicated initial rate of cooling.

ity was drastically reduced.

Temperature of cysts during freezing. The cysts are supercooled to a point considerably below their freezing point when exposed to subfreezing temperatures, but at the time of freezing the latent heat of fusion raises the temperature of the tissue to the freezing point, after which cooling is resumed (figure 2). When we

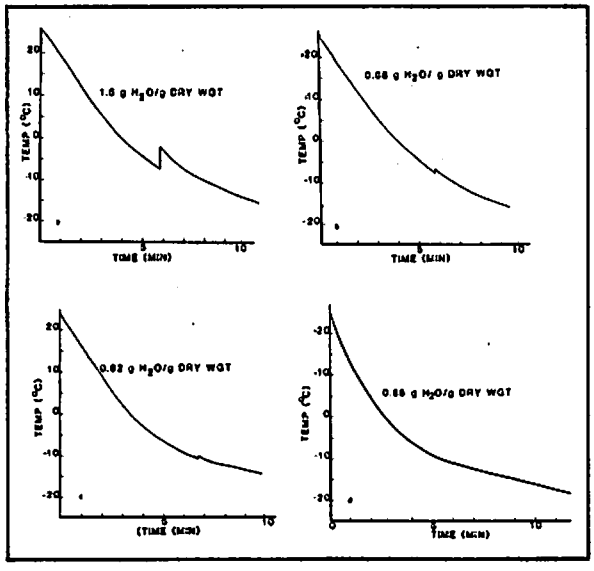

Figure 2. Cooling profile of cysts at different water contents placed in a bath at -24°C.

measured the time course of these temperature changes in capsules of cysts with variable water contents, we obtained results of the type shown in figure 2. A few representative recordings illustrate the most significant trends in the data: with decreasing water content the amplitude of the exothermic spike at freezing is reduced, as is the freezing point. The data from a number of such measurements are summarized in figure 3. These data show that at the highest water contents the freezing temperature is in the region of -2°C, while at the lowest water contents the freezing point falls to about -11°C. Since below 0.6 g H_2O/g dry wgt no exothermic spike could be detected, the curve ends abruptly at that point. When the output from the thermocouple was amplified up to 100-fold, we were still unable to detect an exothermic spike in cysts containing less than about 0.6 g/g. The curve shown (fit by third order polynomial approximation) has a calculated Y-intercept of -13.2°C. Since the bath temperature was -24°C, it seems unlikely that the freezing point of the sample was depressed below the cooling capacity of the bath.

Calorimetric studies. In these studies ice formation was not detected at the lowest water contents (< 0.6 g/g) (figure 4). At higher water contents, however, ice formation increases linearly with water content. When the amount of unfrozen H_2O/g dry wgt was calculated by subtracting from total water content the weight of ice formed, the curve marked "unfrozen H_2O" shown in figure 4 was obtained. These data clearly show that the unfrozen water content remains constant over a wide range of water contents. Between 0.6 and 2.1 g/g the unfrozen water content lies between 0.55 and 0.64 g/g. At lower water contents the amount of unfrozen water decreases linearly.

Leakage studies. Conductivity remained constant in distilled water until previously frozen cysts were added. When cysts with the highest water contents were added, conductivity rapidly rose (figure 5). When cysts with 1.84 g/g were used, for example, conductivity rose from less than 1.0 μmhos/cm to more than 10 μmhos/cm in less than 1 min. By contrast, when cysts with the lowest water contents were used, conductivity rose little or not at all. In the region of 0.6 g/g, a transition is seen between these extremes: when cysts with 0.55 g/g were used, the change in conductivity was barely perceptible, but when cysts with 0.68 g/g were used, an appreciable rise in conductivity was seen (figure 5). When the slopes of the conductivity traces shown in figure 5 were calculated, the curve shown in figure 6 was obtained, which again indicates a transition in the region of 0.6 g/g: in cysts with water contents less than 0.6 g/g, little or no change in conductivity was seen, but at higher water contents conductivity rose abruptly.

Conclusion

There are three clear lines of evidence for discontinuities in the response of *Artemia* cysts to freezing when the water content is elevated from low values to values greater than about 0.6 g/g: (1) At low water contents (<0.6 g/g) the cysts survived prolonged exposure to freezing temperatures, whereas at higher water contents they were killed by freezing. (2) Formation of

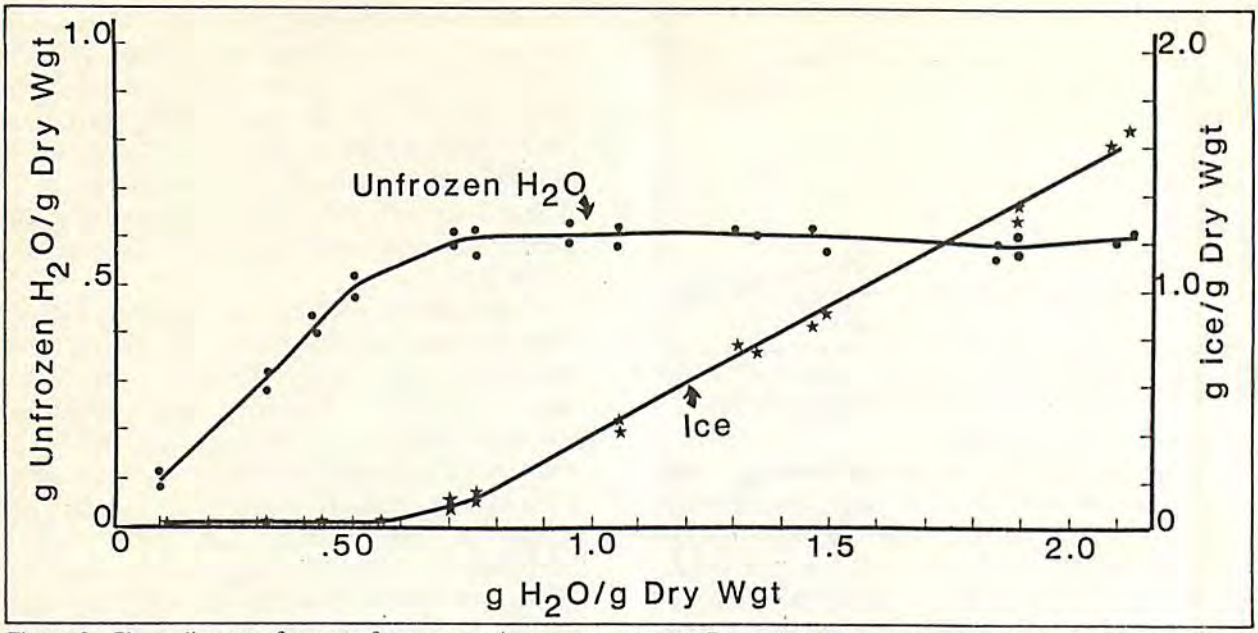

Figure 3. Phase diagrams for cysts frozen at various water contents. Data taken from measurements of freezing points; see figure 2.

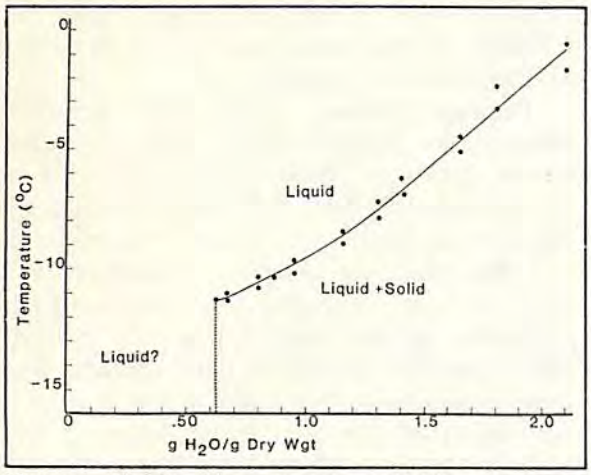

Figure 4. Weight of ice and unfrozen H_2O in cysts frozen with various water contents.

ice was not detected at low water contents, but commenced in the region of 0.6 g/g, increasing linearly with higher water contents. (3) Elevation of conductivity of the medium following freezing of the cysts it contains, long thought to reflect disruption of permeability barriers caused by ice formation in the tissues (cf. Levitt, 1980), does not occur at water contents lower than about 0.6 g/g, but increases dramatically at greater water contents. These data agree with observations that Clegg (1980) obtained with entirely different physical techniques, and we conclude, as has Clegg, that significant amounts of bulk water are not likely to be found in cysts of *Artemia* containing less than about 0.6 g/g.

These data suggest that low-temperature storage of cysts is not likely to affect viability. The unexpectedly high water content required for significant damage to the cysts can only be obtained by immersing the cysts in water before freezing. Since accidental hydration before freezing is almost always from the vapor phase, damage from freezing in most commercial situations is certain to be negligible.

II. Transport of Iron by Adult Female *Artemia.*

Adult female *Artemia* are known to produce both dormant cysts and nondormant ones, which hatch into free-swimming nauplii. It is of interest to aquaculturists to be able to regulate which sorts of cysts are produced, since dormant cysts may be required at one time and continual production of nauplii may be required at another.

Studies in the past have suggested that ferric ion is required to stimulate production of dormant cysts (cf. Clark and Bowen, 1976). Since it was unknown whether the iron acted directly on the animal or even whether it was taken up

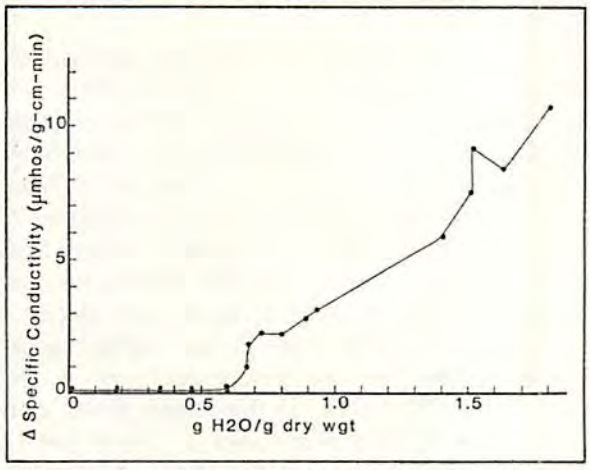

Figure 5. Recordings of conductivity of water following introduction of cysts previously frozen with various water contents.

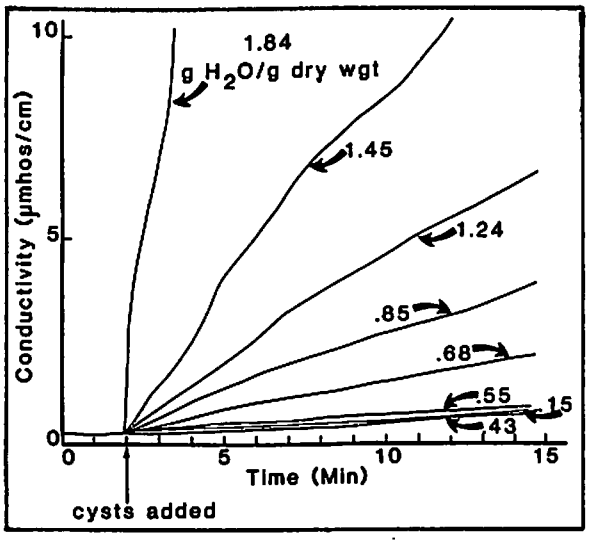

Figure 6. Rates of change of conductivity of medium containing cysts frozen with various water contents.

by the animal, we began with a study of uptake of iron by adult females.

Materials and Methods

Adult females were collected from local salt ponds and kept in the laboratory for three days prior to use. For measurement of iron uptake, we used a stop flow apparatus in the following way. Into the funnel of the apparatus was placed 5 ml artificial seawater containing 0.1 μ Ci $^{59}FeCl_3$ and additional $^{55}FeCl_3$, to provide the desired concentration of Fe^{+3}. At the start of the experiment, 5 ml seawater containing about 10 adult females was pipetted into a funnel and rapidly mixed. At the prescribed time, a vacuum pump removed the water from around the animals. We removed the animals from the filter and transferred them to a tared scintillation vial. After lyophilization and reweighing, scintillation fluid was added, and the amount of Fe^{+3} accumulated by the animals was recorded by liquid scintillation spectrophotometry.

Concentrations of Fe in the salt ponds from which the females were collected were determined with atomic absorption spectrophotometry.

Results and Discussion

Reliable kinetics were difficult to obtain with these animals, mainly because individual variability is large. However, in the system described above, much of this variability is damped because sampling results in average values for a minimum of ten animals. Typical results from this procedure are shown in figure 7. Uptake is linear for at least 10 min, and saturation of the transport system occurs between 50 and 100 μM Fe^{+3}. When the slopes

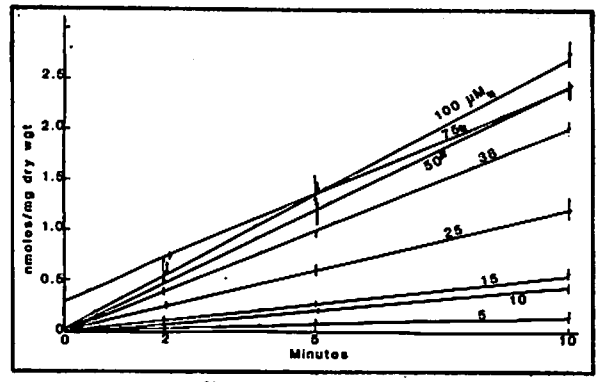

Figure 7. Influx of ^{59}Fe into adult *Artemia*.

of these lines were calculated, the velocity of uptake as a function of substrate concentration could be plotted, as shown in figure 8. The kinetics are clearly hyperbolic, and can be adequately described by Michaelis-Menten kinetic analysis. When such analysis was done, and the data of figure 8 were subjected to linear

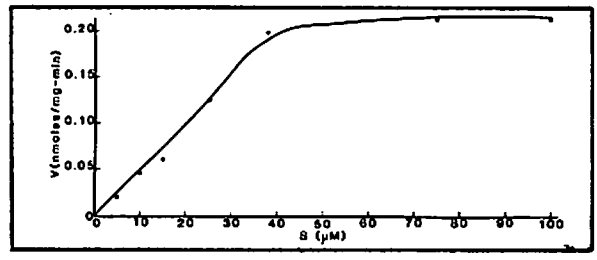

Figure 8. Dependence of velocity of influx of ^{59}Fe on concentration of Fe in the medium.

transformation, kinetic parameters resulting were: V_{max}, 0.22 nmoles (mg-min)$^{-1}$; k_t, 21 μM. Thus, these animals possess a highly efficient transport system for Fe^{+3}.

We found that environmental concentrations of Fe^{+3} in salt ponds varied, depending on where in the pond the samples were obtained. Samples taken near the bottom, in about 1 m water, contained 15-32 μM Fe^{+3}, whereas surface water samples were usually somewhat lower (5-12 μM). Nevertheless, these environmental concentrations are consistent with the kinetic properties of the transport system and suggest that the animals may utilize environmental Fe^{+3}.

We are presently studying the effects of concentration of seawater and O_2 on iron uptake, the site of uptake, and the eventual fate of the iron.

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Evaluation of the Mad River Estuary

Humboldt State
R/NP-1-9C
1979-80

George F. Crandell

The estuarine stretch of the Mad River occurs temporally because of extensive seasonal fluctuation in river flow. A primary goal of this project was to define the extent, character, and duration of the estuary.

In early May of 1979 the salinity intrusion was restricted to the channels in the river below station 3 (figure 1). This stretch of estuary is shallow (much of it less than 1 m). During May, little water remained in this section at low tide except in the few deeper pockets below station 2. Little estuarine environment, where invertebrate populations could establish or salmonids acclimate, occurred until June 10. On that date spring tides and river flow below 70 cfs allowed salt water over a shallow sill below station 3 and into the deeper pools above stations 4, 5, and 6. Once water entered the upper stretch of estuary, the salinity regime remained nearly constant at stations 3, 4, 5, and 6 until October 21, 1979, when high river discharge (249 cfs) completely eliminated the estuary. The upper estuary became established on June 12, 1980, and again coincided with significant spring tides.

The vertical distribution of salinity and temperature demonstrated significant stratification (table 1), which persisted throughout the low-water period. The maximum saline intrusion occurred on July 24, 1979, when 10 ppt water was recorded on the bottom (2.5 m) at station 7 (figure 1).

A second goal of this project was identification and quantification of zooplankton species. Zooplankton within the estuary was dominated by two copepod species, *Halicyclops*, sp and *Eurytemora*, sp (table 2). *Halicyclops*, sp dominated at the beginning of the estuarine period, but *Eurytemora* reached numbers in excess of 100,000/m^3 later in the summer. Zooplankton biomass appears high enough to support numbers of plankton-feeding fish and suggests a high level of primary productivity. Numbers indicate a bimodal change in popula-

Table 1
Salinity (ppt) Distribution in the Mad River Estuary

Date	June 24			August 16			October 19		
River discharge cfs	30.5			28.2			249.1*		
Station	4	5	6	4	5	6	4	5	6
Max. depth (m)	3.25	3.0	3.25	2.5	3.0	3.0	3.0	3.0	3.5
Depth of Halocline (m)	0.5	0.5	0.75	1.25	2.5	0.75	0.8	0.75	0.75
Salinity range above halocline	1.0-15.0	1.0-9.5	0.0-5.1	2.2-20.0	1.2-1.7	1.0-6.0	3.9-20.0	4.0-15.0	1.9-13.0
Salinity range below halocline	15.0-32.0	9.5-23.0	5.1-13.2	20.0-25.2	1.7-3.9	6.0-11.0	20.0-27.5	15.0-25.8	13.0-24.5

*Flow increased after sampling was completed.

Table 2
Zooplankton Numbers/M^3 in the Mad River Estuary

Date	June 24			August 16			October 19		
Station	4	5	6	4	5	6	4	5	6
Halicyclops sp. above halocline	200	950	8,100	40	17	8	8	1,500	415
Halicyclops sp. below halocline	1,500	3,120	2,210	270	50	264	2,220	4,800	996
Eurytemora sp. above halocline	70	135	100	314	10	0	2,074	19,800	2,820
Eurytemore sp. below halocline	560	420	100	456	16	323	31,706	19,000	15,770

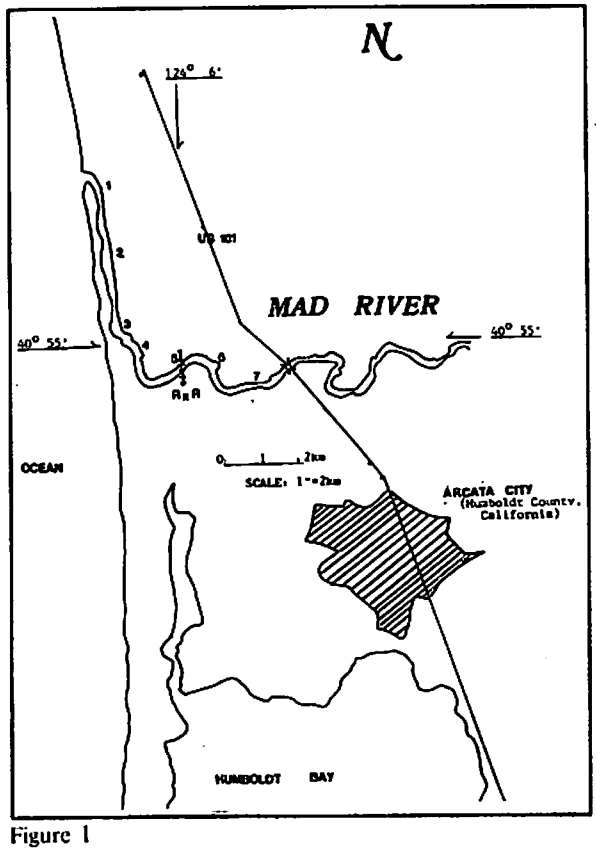

Figure 1

tion density that has not been explained.

Because of the restricted nature of the saline pockets and the sharp vertical gradients in physical and biological characteristics, we developed a portable pumping system for sampling. The system comprised a submersible bilge pump (model TEEL #1P811), a 3/4" smooth-bore hose, and a 12-volt battery. The pump was lowered to depth on the hose and produced 20-25 liters/min of seawater. The system was effective at all depths sampled.

The study successfully defined the Mad River Estuary in terms of salinity and temperature, identified and quantified the zooplankton populations within the estuarine section, and indicated the need for continued investigation of this environment. Additional studies are currently in progress.

Cooperating Organizations
Humboldt Bay Municipal Water District

The Golden Gate Marine Center

Fort Mason
R/NP-1-9D
1979-80

Ron Caya and Marc Kasky

The idea of establishing a "marine learning center" was considered during a two-day workshop sponsored by the Sea Grant College Program and conducted by the Fort Mason Foundation on February 22-23, 1980. At issue was the best use of 100,000 square feet of prime waterfront facilities at the developing community center at Fort Mason, San Francisco, which is part of the new national urban park, the Golden Gate National Recreation Area. (GGNRA).

The workshop brought together people involved in marine affairs in the Bay Area ranging from research scientists to fishermen to oil company spokesmen. More than 190 people participated in the program as speakers or in panel discussions. The workshop was divided into four sessions as follows:

1. The Context of the Golden Gate Marine Center
   - Introduction and Background, Fort Mason Foundation
   - "Developing an Ocean Ethic," Dr. Sylvia Earle
   - Panel Discussion: "What Does the Public Need to Understand about the Marine Environment?" Ron Linsky, Moderator
2. The Content of the Golden Gate Marine Center
   - "Water Within Walls," Dr. Murray Newman
   - Panel Discussion: "Exhibits Simulating the Marine Environment," Dr. John McCosker, Moderator
   - Panel Discussion: "Activities Involving the Public in the Marine Environment," Bill Nobel, Moderator
3. The Constituency of the Golden Gate Marine Center
   - "The Global View," Dr. Sidney Holt
   - "California's Marine Resources," Kevin Shea
   - Panel Discussion: "Involving the Users of the Marine Environment in Public Education," Dr. Michael Herz, Moderator
4. The Community of the Golden Gate Marine Center
   - Boat tour of facilities and programs of the GGNRA in the west central San Francisco Bay.

Dr. Sylvia Earle, Curator of Phycology at the California Academy of Sciences, set the tone and defined the challenge for the workshop and the proposed center in her introductory remarks:

> The time has come to combine the wisdom of science and the sensitivity of art to mold attitudes that will transcend written laws. What is needed is an ocean ethic. It is really up to those of us that know something and who care something about the sea to apply ourselves to the challenge of developing an ocean ethic.

The areas or ideas that were generally agreed upon by the workshop's participants were:

- The need to develop an ocean ethic
- The importance of information for the general public
- The need to affect decision-makers
- The necessity that the center be self-sufficient
- The need to clearly define goals
- The need to examine audiences and involve them in planning
- The need to complement existing programs and institutions
- The need to take advantage of the site's features
- The need to focus on the region.

Areas or ideas that were controversial:

- The percentage of effort in education, research, training, etc.
- The importance of practical or applied content
- The potential of pier use
- The priority of audience to focus on
- The cost effectiveness of exhibits
- The need for planning versus the need to start
- The clearinghouse approach versus designed programs
- The appropriate pier building to use.

The workshop participants generally expressed their interest in the proceedings. However, some participants felt the workshop raised more questions than it answered. Clearly, creating an institution that responds to the escalating importance of human interaction with the marine environment is a challenge that must be met.

Cooperating Organizations
Exploratorium
National Park Service
Oceanic Society

The Role of Nutrients in Supporting Phytoplankton Productivity in Humboldt Bay

Humboldt State
R/NP-1-9E
1979-80

John E. Pequegnat and James H. Butler

Coastal resources management frequently involves deciding about conflicting or potentially conflicting uses. Although the Coastal Act of 1976 outlines specific uses for the coastal zone and defines certain priorities, conflicts still develop. Planning becomes particularly difficult when conflicting uses are both given high priority by the Coastal Act and by subsequent coastal policies. Resolution of this kind of conflict requires an intricate understanding of natural processes as well as legalities. Often, the necessary solid informational base is lacking, particu-

larly when it concerns managing an area's natural resources.

Humboldt Bay, California, is an example of an area with a number of potentially conflicting uses, and which is regulated by numerous federal, state, and local agencies, each with separate definitions and policies. The bay is a major wintering area for ducks and other waterfowl; it supports both sport and commercial fisheries; it is the largest port between San Francisco and Coos Bay, Oregon. Ninety percent of the oysters harvested in California come from Humboldt Bay (Pinkas, 1977), and additional aquaculture--including ocean ranching of salmonids, culture of nori, and culture of mussels--has been proposed (Humboldt County Board of Supervisors, 1978).

The Northcoast Basin Plan identifies thirteen beneficial uses for Humboldt Bay, of which ten depend on sustained productivity. Problems in regulating and managing these uses necessitate this study. Recent investigations (Harding and Butler, 1979; Pequegnat and Butler, 1979) have indicated that the primary productivity of North Humboldt Bay, where commercial oyster beds, a wildlife refuge, and a few wastewater outfalls are located, may be depressed by low nutrient concentrations. If so, decisions about removing nutrient-rich wastewater from this system, expanding the wildlife refuge or other protected areas, introducing new forms of aquaculture, or expanding existing aquaculture must all rely on an adequate understanding of the relationship between primary productivity and nutrient concentrations in Humboldt Bay.

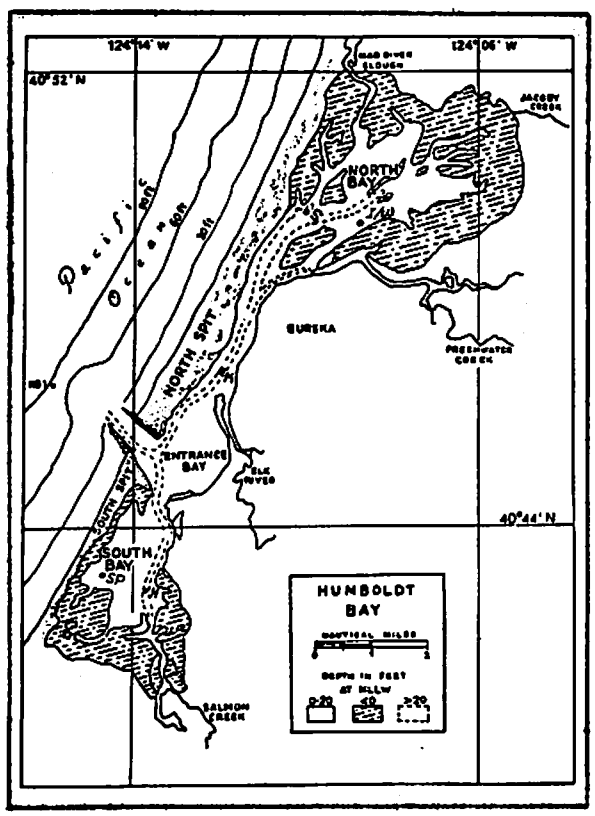

Figure 1. Map of Humboldt Bay, showing sampling locations: Hookton, (H), Southport (SP), Ocean (HB-1), Samoa (S), Main (M), and Indian (I/W).

It is our hypothesis that (1) Humboldt Bay waters are isolated from nearshore waters, (2) because of this isolation, nutrients become limiting to primary production during periods of low runoff even though high nutrient concentrations are found in the nearshore water from upwelling, and (3) wastewater nutrients provide a significant contribution to the bay's nutrient budget.

The purpose of this study, then, is to determine if nutrients limit primary production in Humboldt Bay during periods of low runoff, to determine which nutrient or nutrients limit growth during these times, and to estimate the existing and potential primary production in Humboldt Bay with and without wastewater nutrients. We have sampled to obtain information representative of all three compartments in the bay, and we shall attempt to determine the exchange between the nearshore water and the North Bay compartments. The role of wastewater nutrients in supporting bay productivity will be considered, and aquaculture potential will be assessed in light of this information.

Study Area Description

Humboldt Bay is located along the northern coast of California. The bay has two major subbays, North Bay and South Bay; a minor subbay, Entrance Bay; and channels, most important of which are Entrance Channel and North Bay Channel. The hydrography of the three sub-bays differs significantly.

Entrance Bay is a small shallow area adjacent to Entrance and North Bay channels. The water here has only a transient existence, changing character with each tide, alternately assuming nearshore characteristics at high tide, and North Bay hydrographic characteristics at low tide. Some South Bay water collects in the extreme south portion of Entrance Bay.

South Bay is separated from the nearshore water by the relatively short Entrance Channel. The tidal prism, MHW to MLLW, is 68%. The water covering the mud flat at high tide moves into the South Bay channels (Hookton and Southport Channels) and the southern portion of Entrance Channel at low tide. Since the tidal prism is larger than the low-tide volume of South Bay, there is considerable exchange of water between the bay and nearshore waters

with each average tidal exchange.

North Bay is separated from the nearshore area by a channel 11 km long (Entrance and North Bay channels in line). Even though the tidal prism of North Bay is 44%, the water over the mudflats at high tide is not rapidly flushed from the bay. Rather, the water over the mudflats at high tide simply moves into the channels at low tide, only to be returned to the flats on the subsequent high tide. The nearshore water moves from offshore into the channels at high tide, returning to the nearshore as the tide ebbs. This results in a relative isolation of North Bay water from the nearshore. Although flushing does occur, the exchange is slow enough to allow a unique chemical and biological character to develop.

Techniques and Materials

Field Sampling. Six stations were selected to represent the spectrum of North Bay (Samoa and Indian-Woodley), North Bay Channel (Main), South Bay (South Port and Hookton), and the nearshore (Ocean) waters. Field samples and data were collected at lower low tide within 30 min of the calculated slack water time for each station. Water was pumped from 4 m depth into precleaned bottles. Chlorophyll samples were stabilized with $MgCO_3$ (Strickland and Parsons, 1972), and placed in an iced cooler with the nutrient water samples. Water for the nutrient bioassay experiments, potential productivities, alkalinities, and salinities was collected in a separate, one-gallon, nalgene bottle. Iron samples were collected in acid-rinsed 32 oz glass jars and acidified in the laboratory. Oxygen samples were fixed in the field (Strickland and Parsons, 1972). All samples were brought to the laboratory within two hours of sampling.

Field Productivities. Water for *in situ* productivities was pumped directly into prelabelled, acid washed, 250 ml glass bottles. Samples were suspended from anchored buoys at 0.5, 1.5, 2.5, 3.5, and 4.5 meters. Light attenuation was estimated with a 30 cm Secchi disc, calibrated with a submarine photometer. Incident radiation was monitored daily with a mechanical pyranometer maintained at the HSU Marine Laboratory 15 miles north of Humboldt Bay. Samples were incubated from approximately 0700 to sunset. Samples were kept in the dark and filtered onto GFA filters about 30 minutes after removal from the water. Inorganic C-14 was purged by wetting the filters with 0.25 ml of 10% glacial acetic acid in methanol. Filters were dried 24 hours at 70°C, after which 10 ml of cocktail was added, and the samples were counted. Scintillation cocktails contained 5 grams POPOP and 0.5 PPO per liter toluene.

Laboratory Analyses. Dissolved oxygen, pH, alkalinity, nitrate, nitrite, ammonium, phosphate, silicate, and chlorophyll were analyzed on the collection day. Potential productivity samples were incubated under constant light and temperature, filtered, and the filters dried (techniques were similar to the field methods), and the nutrient bioassays were begun. Salinity samples were drawn into citrate bottles, and iron samples were preserved with acid and stored for analysis at a later date (EPA, 1979).

Except for iron analyses and nutrient enrichment bioassays, all laboratory procedures were modified from Strickland and Parsons (1972). Oxygen was determined by the Winkler method, alkalinity by aliquot addition, and chlorophyll both trichromatically and by acid addition.

Only the dissolved, reactive species of the nutrient elements were analyzed. Except for silicate, which was filtered through a Whatman #1 filter, subsamples for all nutrients were filtered through glass fiber (GF/A) filters. Nitrate was determined by cadmium reduction, nitrite by azodification, phosphorus by the ascorbic acid method, ammonia by the phenol-phenate method, and silicate by silicomolybdate formation. Absorbance for all of these tests was measured with a Perkin Elmer-Hitachi 200 UV-

Table 1
Spectrum of Nutrient Enrichment Used in the Nutrient Bioassays Experiments

Culture	Nitrate	Phosphate	Silicate	Iron
1	-	-	-	-
2	+	+	+	+
3	-	+	+	+
4	+	-	+	+
5	+	+	-	+
6	+	+	+	-
7	+	-	-	+
8	-	+	-	+
9	-	-	+	+
	+	-	-	-
11	-	+	-	-
12	-	-	+	-
13	-	-	-	+

Table 2
Chemical and Physical Characteristics of Six Stations in Humboldt Bay and the Nearshore Water during Upwelling (7/25/80) and Nonupwelling Periods (6/26/80)

6/26/80

	Hookton	S Port	Ocean	Main	Samoa	Indian
Temp	15.5	15.2	12.4	15.7	17.3	
Salinity	33.476	33.527	33.338	33.472	33.285	33.543
Oxygen	4.35	4.29	4.17	3.24	2.93	2.60
Secchi	1.10	1.10	4.00	1.00	0.90	00.80
pH	8.37	8.42	8.33	8.13	8.01	8.03
Chloro	6.04	5.59	13.27	11.38	6.38	5.90

7/25/80

	Hookton	S Port	Ocean	Main	Samoa	Indian
Temp	16.1	15.0	12.5	16.3	17.7	18.5
Oxygen	3.94	3.80	3.55	3.24	3.16	3.29
Secchi	0.95	1.35	1.70	1.33	1.00	1.15
pH	8.18	8.18	8.05	7.96	7.94	7.96
Chloro	6.19	5.45	12.61	7.68	5.69	4.83

Table 3
Nutrient Concentrations at Six Stations in Humboldt Bay and Nearshore Water during Upwelling (7/25/80) and Nonupwelling (6/26/80) Periods

6/26/80

	Hookton	S Port	Ocean	Main	Samoa	Indian
Nitrate (NO_3)	1.9	0.0	0.3	0.5	0.5	0.9
Nitrite (NO_2)	0.03	0.05	0.03	0.07	0.13	0.16
Ammonium (NH_4)	0.2	0.5	0.0	0.8	1.1	1.3
Phosphate (PO_4)	0.79	0.73	0.03	1.27	2.04	1.87
Silicate (SI)	8.9	7.7	2.1	13.5	22.9	22.9

7/25/80

	Hookton	S Port	Ocean	Main	Samoa	Indian
Nitrate (NO_3)	1.6	2.1	12.6	4.0	2.6	1.6
Nitrite (NO_2)	0.05	0.11	0.19	0.21	0.20	0.13
Ammonium (NH_4)	0.9	1.5	1.9	2.3	1.5	1.2
Phosphate (PO_4)	1.44	1.36	1.44	1.90	2.23	2.21
Silicate (SI)	16.5	14.9	19.2	21.9	26.8	26.9

Visible Spectrophotometer, with 10 cm cells for ammonia, phosphorus, and nitrite, and with 1.0 cm cells for nitrate and silicate. To determine precision and accuracy, 18% of the samples were spiked with a known quantity of the nutrient being analyzed, and 18% were run in duplicate.

Samples will be analyzed for iron by atomic absorption following APDC-MIBK extraction (Brooks, 1967; Goldberg, 1976). Since we plan to use a Perkin Elmer 460 double beam spectrophotometer, our limits of detection and sensitivity should be sufficient for these samples.

Nutrient elements tested in the nutrient enrichment bioassays were nitrogen as nitrate, phosphorus, silicon, and iron. Subsamples of filtered seawater from each station were introduced into sterilized flasks, enriched with one or more nutrients in a manner to best determine which nutrient elements can potentially limit phytoplankton growth (table 1), and incubated for five days at constant light and temperature. Sample turbidity was measured at 450 nm on days 1, 2, and 5; turbidities were correlated with cell counts at different stages of growth.

Table 4
Nutrient Bioassays Results for Water Collected at Six Stations in Humboldt Bay during Periods of Upwelling (7/25/80) and Nonupwelling (6/26/80).

6/26/80

	Hookton	S Port	Ocean	Main	Samoa	Indian
1. No nutrients	1.0	1.0	1.0	1.0	1.0	1.0
2. All nutrients	3.89	4.11	2.41	3.95	4.38	4.49
3. No NO_3	0.74	0.83	0.79	0.81	0.82	0.94
4. No PO_4	1.97	2.00	1.28	2.22	2.77	2.94
5. No Si	2.00	2.57	1.55	2.43	2.64	3.06
6. No Fe	0.0	1.63	1.72	2.86	0.0	3.37
7. NO_3 + Fe	1.53	1.74	1.34	2.14	2.54	2.77
8. PO_4 + Fe	0.61	0.80	0.55	0.76	0.69	0.89
9. Si + Fe	0.34	0.80	0.59	0.73	0.69	0.80
10. NO_3	1.63	1.83	1.59	2.16	2.41	2.71
11. PO_4	0.84	1.06	1.07	1.11	0.97	1.17
12. Si	0.89	0.74	0.86	0.89	0.90	1.09
13. Fe	0.68	0.83	0.69	0.78	0.77	1.00

7/25/80

	Hookton	S Port	Ocean	Main	Samoa	Indian
1. No nutrients	1.0	1.0	1.0	1.0	1.0	1.0
2. All nutrients	15.44	11.55	5.13	8.31	11.50	9.21
3. No NO_3	0.33	0.73	0.50	0.31	1.08	0.79
4. No PO_4	5.67	4.64	2.25	4.06	7.08	5.43
5. No Si	8.78	8.09	5.58	5.88	8.00	6.36
6. No Fe	10.67	8.91	1.50	3.63	4.83	8.57
7. NO_3 + Fe	6.00	4.82	2.75	3.69	6.83	4.93
8. PO_4 + Fe	1.11	0.36	0.88	0.88	0.83	0.86
9. Si + Fe	0.33	0.09	0.0	0.19	0.58	0.79
10. NO_3	5.44	5.36	3.38	4.06	6.83	4.00
11. PO_4	1.22	1.00	1.00	1.13	1.17	1.14
12. Si	1.44	0.91	0.25	0.81	0.67	0.86
13. Fe	0.12	0.82	0.50	1.19	0.67	0.93

The results are expressed as a ratio of the test nutrient mix to the no-nutrient control. The nutrient mixes are given in table 1. Numbers greater than one represent enhancement by the nutrient mix. Nitrogen is the most important nutrient element tested.

Results and Supposition

The results support the hypothesis that Humboldt Bay waters differ significantly from the nearshore waters and that nitrogen is in low concentrations, quite possibly limiting primary production in the bay waters (table 3). Nutrient bioassays show nitrogen to be the nutrient that first limits growth (table 4).

These low nitrogen concentrations are apparent even though Arcata and Eureka are presently discharging enough ammonium- nitrogen to add 0.5 microgram atoms nitrogen per liter of North Bay and Channel water per day (recalculated from Pequegnat and Butler, 1979).

Analyses of the data in terms of total bay productivity, the quantification of wastewater nutrient contribution, and the impact of removing wastewater nutrients on oyster aquaculture in North Bay are in progress.

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Cooperating Organizations

Humboldt State University

Multispecies Aspects of CalCOFI 1955-1959 Ichthyoplankton Data: A Source of Information for Variations in California Current Fisheries Resources

Valerie J. Loeb

S.D. Natural History Museum

R/NP-1-9F
1980

An extremely interesting block of CalCOFI (California Cooperative Oceanic Fisheries Investigation) ichthyoplankton data was collected during 1955-1959. The period was hydrographically variable: the California Current system exhibited a sequence of anomalously cold (northern influence) and then anomalously warm (southern influence) conditions. Also during this time, northern anchovy stocks rose from very low levels to dominance in coastal waters. Of particular interest to fisheries biologists are the effects that these extreme hydrographical and biological conditions had on the overall composition, abundance, and geographical distributions of the more than two hundred larval fish species in the CalCOFI area.

Heretofore, the 1955-1959 data existed on original larval fish identification sheets and was unavailable for any comprehensive analysis. Additionally, many of the taxonomic designations appearing on these sheets were inappropriate by modern standards. The goal of this project was to update and assign appropriate Southwest Fisheries Center (SWFC) numeric codes to the taxonomic designations on the original identification sheets and to then computerize these codes along with associated counts and sampling information.

The work has been progressing well. At present the data from approximately 9,200 CalCOFI samples collected on 60 cruises have been entered into the SWFC Tektronix computer system. These data, filling four computer discs, have been checked and corrected; they must now be transferred from the Tektronix disc files to the UC San Diego Burroughs 6700 computer system, rechecked for errors, and then formatted into data blocks appropriate for analysis.

Cooperating Organizations

San Diego Natural History Museum
Southwest Fisheries Center

Sea Cliff Erosion and Beach Accretion Along San Onofre State Park and Camp Pendleton, San Diego County, California

UC San Diego
R/NP-1-9G
1979-80

Francis P. Shepard and Gerald G. Kuhn

Most development along the southern California coast has taken place during a period of unusually dry and benign climate, from 1946 to 1977. Tree-ring data spanning the last 400 years indicate this has been the driest period since 1520. During the past 170 years southern California has experienced four wet periods, all exceeding ten years in length.

Our research suggests that greatly accelerated rates of erosion may be expected during wet periods, resulting in unprecedented levels of property damage.

The study area, which encompasses San Onofre State Park and a small segment of Camp Pendleton, is located in the north-central portion of the Oceanside Littoral Cell, which extends from Dana Point in Orange County south to La Jolla Submarine Canyon in San Diego County (figure 1).

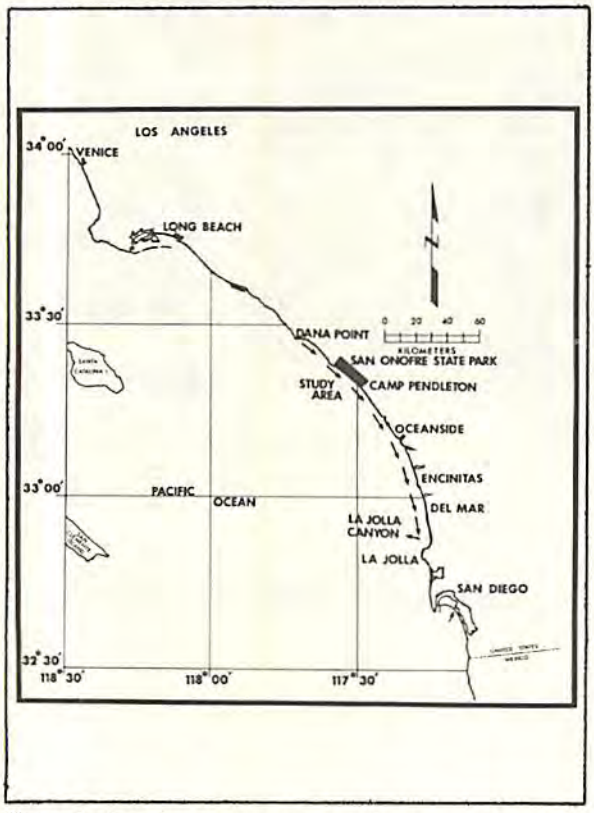

Figure 1. Location map showing study area. Arrows indicate primary longshore current direction between Dana Point and La Jolla Canyon in the Oceanside Littoral Cell.

During the wet winters of 1978-1980, coastal erosion rates have accelerated. Our study has documented erosion of the sea cliffs, bluffs, and canyon heads along this area and reveals that such erosion is catastrophic, episodic, site-specific, directly related to the prevailing meteorological conditions and, in recent years, to human alteration of natural drainage patterns.

Figure 2. "Before" photo, taken in 1954. Oblique view along the bluff at San Onofre State Park. (Photo: U.S. Navy)

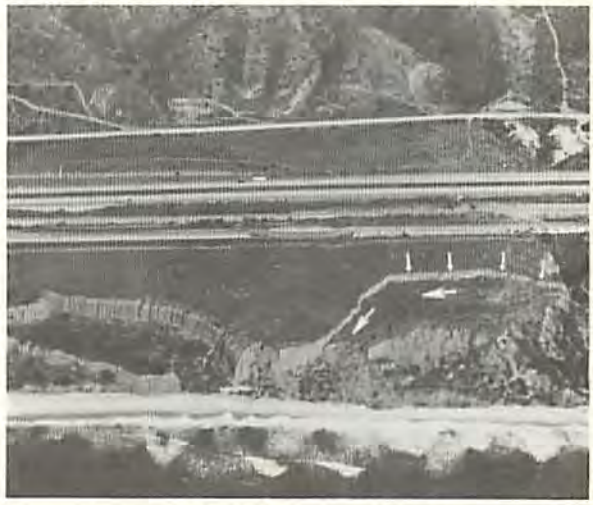

Figure 3. "After" photo, taken in February 1980. Landslide, measuring 700 feet long by 300-320 feet wide, occurred during the winter of 1978. Small arrows point to head scarp, and large arrows indicate direction of debris movement toward beach. (Photo: SIO Photo Lab.)

Erosion under Natural Conditions

Approximately 80% of the cliff along the San Onofre State Park south to Camp Pendleton consists of landslides. This appears to be directly related to periods of intense sediment saturation and large storm swell. A landslide measuring

1700 ft long and 350 ft wide occurred in June of 1941 during a wet, stormy period. More recently, a landslide measuring approximately 700 ft long and from 300 to 320 ft wide occurred during the winter of 1978 (figures 2 and 3). The debris of this slide continues to move seaward as the slope toe is removed by wave action. In addition, erosion of the bluff face contributes fans of debris that move directly onto the beach and are soon reworked by wave action.

Population-Induced Accelerated Erosion

Accelerated headward erosion takes place along all existing paleo-drainage avenues where culverts have been constructed under railroad tracks and highways. From January through April 1978 and again in February of 1980, when rainfall totals were greater than normal, headward erosion accelerated along certain altered drainage avenues. At Horno Canyon, the southbound lanes of Highway 101 collapsed, leaving a 75-ft-deep vertical scarp.

At one location no canyon existed perpendicular to the shoreline before the 1969 storms (figure 4). Between 1968 and 1976 a new canyon was cut headward at this location about 60 ft. During January and February of 1978 approximately 160 ft of headward erosion occurred (figure 5). On February 14, 1980, 5 ft of headward erosion occurred, and on February 20 the canyon eroded approximately 235 ft landward, 50-100 ft deep and 60-90 ft wide (figures 6 and 7). This amounted to about 50,000 cubic yards of sedimentary material, which immediately moved out onto the beach.

Figure 4. 1954. Oblique photo of canyon along the bluffs at San Onofre State Park. (Photo: U.S. Navy)

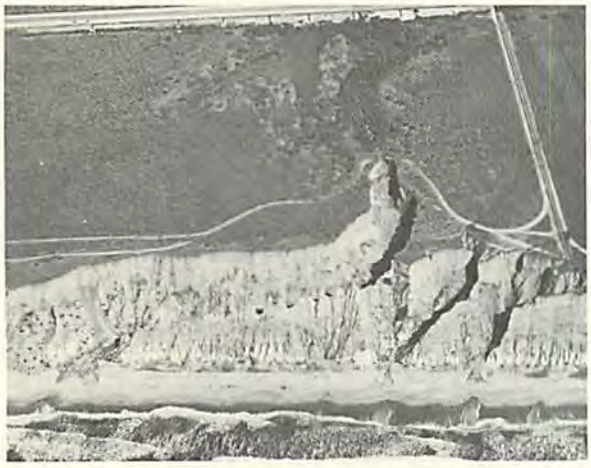

Figure 5. Same location in February 1980, showing canyon head location. Headward erosion is visible. (Photo: Sea Grant)

Dead Dog Canyon, south of Horno Canyon on Camp Pendleton, experienced approximately 560 ft of headward erosion between 1932 and 1977. This same canyon eroded another 100 feet during a two-week period during January and February 1978 and approximately 100 ft in February 1980.

Figure 6. Same area in March 1980. Vertical photo of erosion along the canyon head and subsequent canyon wall collapse. The area located between the large arrows eroded headward approximately 460 feet between January 1968 and March 1980. The area between the small arrows eroded approximately 235 feet on February 20, 1980. (Photo: U.S. Navy)

Conclusions

Coastal erosion and beach accretion along the study area are the direct result of both

natural and population-induced causes. During the recent wet years of 1978-80, erosion has accelerated at canyon heads. Placement of storm drains and culverts beneath the railroad bed and highways has increased erosion rates by concentrating surface water runoff along preexisting drainage avenues. As much as 460 ft of headward erosion occurred on one canyon between 1968 and 1980. Also, landslides are activated during wet years. Both canyon-head erosion and landslides are presently contributing significant quantities of sand to the beaches in the Oceanside Littoral Cell. It had previously been believed that most beach sand in the Oceanside Littoral Cell was supplied by rivers in flood, with only minor contributions from other sources.

Figure 7. February 1980. Canyon cut into unconsolidated bluff, forming terrace deposits at San Onofre State Park. (Photo: Sea Grant)

Publications

Kuhn, G.G., E.D. Baker, and C. Campen. Greatly accelerated man-induced coastal erosion and new sources of beach sand, San Onofre State Park and Camp Pendleton, Northern San Diego County, California. *Shore and Beach* 48(4): 9-13 (1980).

Kuhn, G.G., and F.P. Shepard. Coastal erosion in San Diego County, California. In *Proceedings of Coastal Zone '80 Conference*, November 17-20, 1980, Hollywood, Florida (1980).

Kuhn, G.G., and F.P. Shepard. Greatly accelerated coastal erosion and beach accretion, San Diego County, California. Abstract and paper presented at 6th Annual Coastal Society Conf., October 13-15, 1980, San Diego, California (1980).

Cooperating Organizations

Department of Parks and Recreation, State of California

Pathology and Bacteriology of a Disease of Crustaceans Caused by a Marine Bacterium

Paul Baumann and Paul Bowser

UC Davis/Bodega Marine Lab

R/NP-1-9H
1980

The objective of our project has been to identify a microorganism known to cause disease in lobsters, and which could cause problems in the aquaculture industry.

We surveyed physiological traits of BML-1, a bacterium that is pathogenic for crustaceans. We performed a nutritional screening of 150 carbon compounds, as well as other tests. The data for BML-1 was collated with data from representative strains of marine bacteria and was subjected to a numerical analysis. By this method we identified BML-1 as a strain of *Vibrio alginolyticus*. The identity of the crustacean pathogen was confirmed independently by the results from quantitative microcomplement fixation with the enzymes alkaline phosphatase and superoxide dismutase.

We tested three strains of *V. alginolyticus* for infectivity and established that not all strains are pathogenic for lobsters.

Bacterial virulence often correlates with the presence of a plasmid, so the DNA from BML-1 was screened for plasmids by agarose gel electrophoresis. A number of plasmids were observed, one of which may be required for the pathogenicity of BML-1 against crustaceans.

Aerial Survey of Humboldt Bay, California

Humboldt State
R/NP-1-9I
1979-80

James W. Stork, Steven L. Costa, and John E. Pequegnat

The major goal of this project is to acquire eight hourly series of aerial photographs of Humboldt Bay at eight sequential tidal heights. The photographs will be used to accurately determine the surface area of the bay over a tidal cycle.

Although severely delayed by a lack of congruence between good weather for aerial photography and an appropriate tidal range at the proper time of day, we have taken all the photographs. The first four series are being analyzed; the last four series are being processed by Air Data Systems of Fortuna, California.

The Regional Water Quality Control Board has expressed great interest in acquiring the data when they become available.

Mobile Marine Science Outreach Program

CSU Long Beach
R/NP-1-9J
1980

Roger D. Bauer and Barbara A. Katz

The goal of this project was to develop exhibits and educational materials to be placed in a mobile van. The van will visit school and community groups to give them an opportunity to learn about marine science and the marine environment.

We have remodeled a 26-foot van to convert it to a mobile science museum. We painted the exterior of the van and installed an awning to provide a cover for outside displays. Our shop remodeled the interior, built new cabinets and shelves, and installed a new vinyl floor. All work is complete except for some refitting of the electrical system.

A workshop, cosponsored by the Marine Advisory Program, was held in July to discuss display ideas and methods. Nineteen people attended, including faculty, students, Sea Grant Program representatives, and members of the Los Angeles County Superintendent of Schools office.

Mike Schaadt, a graduate student in marine biology, was hired to develop displays. He has prepared a touch tank with a number of living specimens, and demonstrations of bioluminescence, the uses of kelp, and how fish breathe. The displays are designed to provide as much "hands-on" experience as possible.

We held preliminary exhibitions on campus and at a few selected schools to test the displays. Our first community exhibit took place on October 18.

A Preliminary Survey of the Impact of Limited Entry Regulations upon California Fishermen

UC San Diego
R/NP-1-9K
1979-80

John S. Petterson and Frederick G. Bailey

Government regulations known as limited entry are the focus of our survey. Limited entry (LE) policies restrict access to fisheries. They have had an impact not only upon resident fishermen where they have been introduced, but also upon fishermen who reside far from the regulated fisheries and migrate annually to exploit these resources. The relationship between the California fishermen and the Bristol Bay fisheries in Alaska is an example of such a phenomenon. Our goal was to define the real harm or benefit that LE has brought these fishermen who migrate seasonally to exploit the Alaskan salmon resource.

This project involved three months of field research: two months--June 21, to August 23, 1980--in the Bristol Bay area (principally in Naknek and Dillingham) and one month--August 25, 1980 to 'September 27, 1980--in Pittsburg and Monterey, California. Detailed interviews were collected from thirty California limited entry permit holders fishing the Bristol Bay red salmon runs. Twenty-two other interviews were collected from the Pittsburg/Monterey area.

A total of 1717 fishermen hold drift gill net permits (this study does not consider set net permits, which are held by few California fishermen) to fish Bristol Bay. Of this number, 728 are nonresidents of Alaska. It has been

estimated that Californians make up nearly 42% of captains fishing in Bristol Bay. But statistical data obtained from records of the Limited Entry Commission of Alaska show that less than 30% of the nonresident permit holders, or 12% of the aggregate number of permit holders, are California residents: a total of 216 permits were, as of January 5, 1979, held by Californians. Between 1975 and 1979 a total of 245 Bristol Bay limited entry permits have been held, at one time or another, by Californians. Of that number, 157 are still held by the original owners; 8 have been purchased from outside of California; 51 have been transferred within California; and 29 have been sold out of the state. This amounts to a net loss of 21 drift net LE permits by the fishermen of California.

Records indicate no major interstate transfer patterns. In order of importance, transfers of permits among Californians occur between fishermen of (a) the same ethnic community, (b) the same region or area of California (62% live in the same physical community--in many cases within blocks of each other), or (c) between fishermen residing in four particular urban areas: Monterey, Pittsburg, San Pedro, and San Francisco.

The consensus among California fishermen is that LE benefits the physical resource and, as a consequence, the economic stability of the fisherman. Superficial observation of residences--if used as an index of standard of living--would support this conclusion.

Limited entry has resulted, indirectly, in increased pressure on alternative fishery systems. For example, fishermen who obtained record returns from the 1979 red salmon run were motivated (as a result of tax laws that favored investing surplus profits to avoid paying very high taxes) to invest in improved gear. This heavy investment in, for example, a new vessel, made it imperative that they attempt to assure adequate returns in 1980--and to do so they felt they must fish herring. As a result, an excessive number fished herring, and the average fisherman failed to make expenses.

Most fishermen, while admitting they saw their permits as a windfall profit, also felt that the value currently placed on the permit (approximately $100,000) was "not unreasonable compared with the return on investment."

We found no fishermen who could claim to have been excluded as a direct consequence of the enactment of LE in Alaska. This is because their experience of using several different fisheries (e.g., in California and Washington) over the course of the year enabled them, as a group, to gauge the potential consequences of LE policies and to take actions necessary to insure their inclusion. In most cases, this involved establishing a history of resource utilization that would eventually form the basis of their right to continue fishing. This was fully compatible with their traditional adaptive strategy of maintaining the maximum number of fishing options.

For those fishermen who considered this avenue unprofitable (since the fishery was particularly unproductive during early efforts to establish LE), other approaches were available. For example, prior to the implementation of LE, they sold fish on other fishermen's licenses to insure future access to the resource on the chance--for some, the expectation--that LE would be enacted in Bristol Bay. This strategy continues to be applied today in the Togiak herring fishery, with the expectation that it too will soon come under LE regulations.

We also found that Alaska's limited entry regulations were designed expressly to improve efficiency. California fishermen have, on the whole, benefited most from this objective since they have traditionally been in the forefront in using capital intensive technological advances.

Ova Development Success as a Function of Temperature and Delay in Fertilization Post Spawning

Humboldt State
R/NP-1-9L
1980

Earl E. Ebert, Randall M. Hamilton, and John D. DeMartini

Induced spawning techniques for the red abalone *Haliotis rufescens* have been largely perfected by using either heavily irradiated seawater, or hydrogen peroxide. However, spawnings may not be synchronous, or various factors may intercede to delay gamete mixing. It is generally known that gamete viability is affected by fertilization delays. Also, a relationship exists between gamete viability and temperature. The purpose of this study was to determine the development success of the red abalone as a function of the fertilization delay time period, relative to temperature, and to compare ova and sperm for duration of viability.

From July 1980 through September 1980, 24 experimental runs were conducted at the Cali-

fornia Department of Fish and Game, Marine Culture Laboratory, Monterey. We used heavily irradiated seawater to induce abalone to spawn. Synchronously spawned gametes were independently retained until time of gamete mixing at selected test temperatures of 9°C, 12°C, 15°C, 18°C, 21°C (±0.5°C).

At either temperature extreme (9°C and 21°C), replicate tests produced rather wide variations. Mean test values at 9°C revealed that approximately 50% fertilization success occurred when gametes were mixed within 30 minutes after spawning. However, after 1 hour, fertilization success declined to about 23% and was less than 1% after 4 hours. At 21°C, fertilization success was approximately 63% when gametes were mixed within 30 minutes, and about 16% after 1 hour. Successful fertilization did not occur 2 hours after spawning.

The intermediate test temperatures (12°C, 15°C, and 18°C) revealed less variation between test replicates. Gametes that were mixed within 1 hour at 12°C and 15°C resulted in 96% to 100% fertilization success. At 18°C, fertilization success was somewhat lower for this same time interval, and averaged about 85%.

Gamete mixing delays of 2 hours at 18°C resulted in less than 50% fertilization success, and after 4 hours success was zero. Gamete viability retention time was best at 12°C and 15°C. At these temperatures fertilization success remained relatively high, between 80% and 90%, with 3-hour gamete mixing delays. However, 6-hour delays in gamete mixing at 12°C and 15°C revealed only approximately 2% to 3% fertilization success. The longest gamete viability retention time from synchronously spawning parent stock occurred at 12°C, when nearly 2% fertilization success was noted after 8 hours.

Testing to compare sperm and ova viability loss was conducted at 15°C. Spermatozoa lost their viability faster than did ova. Six-hour-old ova inoculated with fresh sperm suspension resulted in 72% fertilization success. However, 6-hour-old sperm at this same test temperature revealed only about 3% fertilization success. Overall, the results of this study indicate that 15°C is the optimum spawning induction temperature, inasmuch as gamete mixing can be delayed up to 3 hours and still achieve the highest fertilization success (90%). Furthermore, at this same temperature (15°C), ova can be fertilized by fresh sperm up to 6 hours after spawning with reasonably good results.

Cooperating Organizations
California Department of Fish and Game, Marine Culture Laboratory, Monterey

Bioelectric Toxicity Assaying (Phase I)

UC San Diego
R/NP-1-9M
1979-80

Victor C. Anderson

Testing of individual chemicals and pesticides for toxic effects, especially for sublethal effects, is currently lagging behind the introduction of new chemicals. Because of time lags between introduction, ecological effects, regulation, and removal from the environment of toxic substances, laboratory testing is required. Current bioassaying techniques for invertebrate toxicity are (skilled) labor intensive and expensive. Electronic monitoring of behavior has the potential of being automated and greatly reducing cost.

The objective of this project is to develop a means of measuring bioelectric signals as a tool for evaluating pesticide toxicity in gastropods. The myoelectric signals of intact, unoperated gastropods will be recorded and analyzed for changes in amplitude, spectral content, and spatial correlation, in response to chronic exposure to pesticides.

We have designed an array of high gain and high input impedance amplifiers. Printed circuit boards have been made; amplifiers and array are under construction. In addition, we have prepared a precision array of electrodes on 5 mm centers.

Concurrently, we are maintaining ten *Cerithidea californica* in an eight-litre aquarium to evaluate them as test species for use with the array.

A Preliminary Investigation of Indochinese Refugee Adaptation to the Monterey Bay Fishing Industry

UC Santa Cruz
R/NP-1-9N
1980

Michael Orbach

The recent influx of Indochinese fishermen into the California fishing industry has caused considerable controversy. In addition to the fact that few of them speak English proficiently, the Indochinese have different fishing techniques and styles, different perceptions of the relationship between man and the marine environment, and exhibit different socioeconomic and cultural patterns from those which predominate in California. In several recent instances these factors have led to social, economic, and physical conflict between Indochinese and non-Indochinese fishermen. Certain of these conflicts are due to misunderstanding or lack of information, and others are the result of more basic differences in culture, economy, and occupational lifestyle.

This project has used ethnographic research to address some of these misperceptions and information gaps and to define basic socioeconomic and cultural differences. Records on 120 Indochinese fishermen were compiled, and a stratified sample of 17 in-depth, series interviews was carried out on boats and in other fishing-related locations, and in homes. Information was also obtained from literature searches, government offices, and other fishing industry sources.

One of the primary areas of misunderstanding was found to be the non-Indochinese fishermen's perceptions of government benefits available to refugees, specifically government-subsidized commercial boat loans. It was rumored that besides receiving substantial income benefits from the government, the refugees were getting privileged access to loans at very low rates (2% annual interest, by one rumor). Through our research, we found that only one of the approximately forty Indochinese boats in Monterey Bay was obtained with a commercial loan, and that that loan was not government-connected. The capital for these boats and gear had in fact been amassed through a socioeconomic structure very common throughout Southeast Asia and other parts of the world: personal loans and investment through family and community networks of reciprocal obligations. Many people may invest in a given boat and its gear, with proportional benefits from the fishing operation going to each investor. It was important to actually trace some of these relationships. The rumors were so strong that it was not enough to assure the non-Indochinese fishermen that the government was not subsidizing loans; it was also necessary to explain how the refugees, many of whom outwardly appear to have few individual or nuclear family assets, were purchasing fishing boats.

A second area of concern involved differences in technical skills and boat handling techniques. Many of the Indochinese fishermen were used to dealing with small Japanese diesel engines rather than the gasoline engines in the boats they are using here. This, in combination with our complex safety and equipment inspection requirements, resulted in several citations by enforcement personnel and serious problems involving life and property. (One boat sank at sea with three people lost; another burned in Monterey Harbor, and so on.) In addition, the boat handling styles and cosmetic maintenance values of the Indochinese tend to be different from those of many local fishermen. These factors required education not only in formal safety requirements, but also in U.S. boating etiquette.

A third misunderstanding revolved around perceptions of the human relationship with, and use of the marine environment. Several Indochinese were cited over the summer 1980 for fishing in sanctuary areas. Part of this was due to the fact that the areas were not marked physically or on charts. In addition, the Indochinese were unable to read and understand the complex California fishing regulations. It is difficult for them to understand the sanctuary concept in cases where noncommercial uses are not apparent and where there does not appear to be a pressing need to protect any particular resource. The Indochinese come from a war-torn environment where locally harvested natural resources in many instances form the major part of one's sustenance. The environmental protection ethic that has evolved in the complex political and economic systems of the U.S. is very different from this. The Indochinese are learning the formal rules, but cultural differences such as environmental ethics are more difficult to express and to address.

The situation is far from stable. There have

been some confrontations between Indochinese and "locals" in recent months, and in the middle of October one of the most successful and well-equipped of the Indochinese boats was sunk under questionable circumstances in Monterey Harbor. There have also been threats to facilities that service Indochinese fishermen and their boats, and several cases of vandalism and theft have been directed at the Indochinese.

This project has addressed some of the social, economic, and cultural aspects of these problems, but a sustained effort will be required to document them and their role in what promises to be increasing participation by Indochinese immigrants in U.S. fishing industries.

Cooperating Organizations

Monterey Indochinese Resettlement Assistance Program

Sea Grant Program Summary

Project Title (Project Number, Project Leader)	FY78	FY79	FY80
MANAGEMENT			
Program Management (M/A-1, Sullivan)	O	O	O
Program Planning and Development (M/P-1, Sullivan)	O	O	O
EDUCATION			
Sea Grant Trainees (E/G-2, Sullivan)	O	O	O
Marine Education: Undergraduate Independent Research (E/UG-1, Doyle)	O	C	--
Development of a Prototype Course in Marine Policy (R/NP-1-8D, Sorensen)	--	N/C	--
A History of the Santa Barbara Channel (E/UG-2, Talbott)	--	--	N
Ocean Engineering and the Future: Long-Range Planning A Graduate Seminar (E/G-8, Webster/Tulin)	--	--	N/C
ADVISORY			
Ocean Education for the Public (A/PE-1, Wilkie et al.)	O	O	O
Marine Advisory Program (A/EA-1, Cummings)	O	O	O
Publications and Public Advisory Services (A/P-1, Frautschy)	O	O	R
Communications, Publications, and Public Advisory Services (A/P-1, Sullivan)	--	--	R
The Golden Gate Marine Center (R/NP-1-9D, Caya)	--	--	N/C
Mobile Marine Science Outreach Program (R/NP-1-9J, Bauer)	--	--	N
COASTAL RESOURCES RESEARCH			
Coastal Wetlands Management: Biological Criteria (R/CZ-33A, Holmes et al)	O	C	--
Coastal Wetlands Management: Effects of Disturbance on Estuarine Function (R/CZ-33C, Zedler/Mauriello)	O	C	--
Coastal Wetlands Management: Opening of Coastal Lagoons by Sand Fluidization (R/CZ-33D, Inman/Nordstrom)	C	--	--
Thermal Variability in Coastal Waters in the Southern California Bight (R/CZ-31, Winant)	O	C	--
Internal Waves Over Shelf and Canyon (R/CZ-32, Cox)	C	--	--
Development of Interpretive Methods and Materials for Marine Parks in Northern California (R/MR-1, DeMartini)	C	--	--
Geological and Historical Analysis of Coastal Zone Environmental Hazards and Liability for Losses Caused by Them (R/CZ-43, Shepard/Hildreth)	N	C	--
Kelp Bed Mariculture and Resource Management (R/A-16, Neushul et al.)	C	--	--
Kelp Forest Ecology of Central California (R/A-16C, Pearse)	O	C	--
Coastal Governance 1977-1978: First Steps in Implementing California's 1976 Legislation (R/CZ-41, Lee/Scott)	N/C	--	--
Coastal Zone Management: Methods for Plan Development, Evaluation and Monitoring of Local Programs (R/CZ-42, Dickert)	N/C	--	--
Wetlands Management in Coastal Zone Planning: A Prototype Framework for Relating Natural Science and Land-Use Planning (R/CZ-45, Dickert/Nybakken)	--	N	C
An Experimental Program to Develop Methods for Kelp Bed Expansion and Enhancement (R/CZ-46, Neushul/Coon)	--	N	C
A Study of the Entrance Problems at Humboldt Bay (R/CZ-47, Isaacs/Kerstetter)	--	N	C
Coastal Governance in California, with Special Reference to State-Local Collaborative Planning (R/CZ-49, Lee/Scott)	--	N/C	--
Feasibility Study of *in situ* CPR Using SCUBA-ERR (Emergency Regulator Resuscitation) and Closed-Chest Cardiac Massage (R/NP-1-8A, West)	--	N/C	--
Dioxins--Historical Record of Fluxes in Lake Michigan Sediments (R/NP-1-8C, Goldberg)	--	N/C	--
Coastal Wetlands Management: Review of and Recommendations about Local Plans (R/NP-1-8E, Onuf)	--	N/C	--
Methods of Increasing Diver Effectiveness Through CO_2 Absorbers and Decompression Computers (R/NP-1-8F, Mote)	--	N/C	--

Project Title (Project Number, Project Leader)	FY78	FY79	FY80
COASTAL RESOURCES RESEARCH (continued)			
Wetlands Restoration Option Study--Ballona Wetlands (R/NP-1-8G, Clark)	--	N/C	--
Recreation Transportation Analysis for Coastal Planners: A Technical Report on the Methods Used in California (R/NP-1-8H, Kanafani)	--	N/C	--
Feasibility Study to Assess the Development of an Applied Marine Research Directory (R/NP-1-8K, Sorensen)	--	N/C	--
Acoustic Tomography (R/CZ-P-1, Munk et al.)	--	N/C	--
Coastal Wetlands Management: Restoration and Establishment (R/CZ-51, Zedler)	--	--	N
Coastal Wetlands Management: Application of Biological Criteria (R/CZ-52, Onuf et al.)	--	--	N
Investigation of Coastal Bluff Retreat for the Trinidad Headland Area of Northern California (R/CZ-53, Carver)	--	--	N/C
Analysis of Coastal Ocean Mixing Models (R/CZ-48, List/Morgan)	--	--	N
Phosphorites Along the Central California Continental Margin (R/CZ-54, Mullins)	--	--	N
Evaluation of the Mad River Estuary (R/NP-1-9C, Crandell)	--	--	N/C
The Role of Nutrients in Supporting Phytoplankton Productivity in Humboldt Bay (R/NP-1-9E, Pequegnat)	--	--	N/C
Sea Cliff Erosion and Beach Accretion Along San Onofre State Park and Camp Pendleton, San Diego County, California (R/NP-1-9G, Shepard)	--	--	N/C
Aerial Survey of Humboldt Bay, California (R/NP-1-9I, Stork/Costa)	--	--	N/C
AQUACULTURE RESEARCH AND DEVELOPMENT			
Protective Measures for Shellfish Aquaculture (R/A-15, Steenbergen)	C	--	--
California Aquaculture Law (R/A-13, Bowden)	C	--	--
The Development of the Science and Technology of Aquaculture (R/A-19, Hand)	C	--	--
Use of Thermal Effluent in the Culture of Crustacea and Fishes (R/A-21, Van Olst/Ford)	O	C	--
Biochemical and Genetic Control Applied to the Critical Stages in Culturing Abalone (R/NP-1A, R/A-25, Morse)	C	--	--
Aquaculture of the Purple-Hinge Rock Scallop (R/R-7, R/A-24, Phleger/Leighton)	C	--	--
Carrageenophyte Cultivation, Genetics, Population Dynamics, and Development of Agar Substitutes (R/A-17, Doyle et al.)	C	--	--
Genetic Program for Improvement of Carrageenan Production in *Gigartina* (R/A-17B, West)	O	C	--
Toward Seawater-Based Crop Production (R/A-22, Epstein)	O	C	--
Astaxanthin from Yeast for Fish Diets (R/R-11, R/A-27, Lewis)	C	--	--
Control of Reproduction in the Lobster (R/NP-1-7B, Talbot)	N/C	--	--
Development of the Science and Technology of Crustacean Aquaculture (R/A-28, Clark/Hand)	--	N	O
Control of Reproduction in the Decapod Crustaceans (R/A-29, Talbot)	--	N	O
Studies to Refine Hatchery and Ocean Rearing Methods for the Purple-Hinge Rock Scallop (R/A-31, Phleger/Leighton)	--	N	C
Biochemical and Genetic Control of Critical Physiological Processes in Molluscan Life-Cycles: Basic Mechanisms, Water-Quality Requirements, and Sensitivities to Pollutants (R/A-32, Morse)	--	N	C
Aquaculture of Red Algae (R/A-34, Abbott)	--	N	C
Culture of Marine Bivaves: Effects of the Uptake of Amino Acids (R/A-33, Stephens)	--	N	O
An Exploratory Study of the Vegetative Propagation of Benthic Marine Algae (R/A-37, Gibor/Neushul)	--	N	O

Project Title (Project Number, Project Leader)	FY78	FY79	FY80
AQUACULTURE RESEARCH AND DEVELOPMENT (continued)			
Investigations of Population Genetic Structure in Abalones (R/NP-1-8B, Hedgecock/Morse)	--	N/C	--
Procurement of Wildstock Sturgeon (R/NP-1-8J, Clark/Doroshov)	--	N/C	--
Protective Measures Against *Fusarium* Disease in Shrimp (R/A-38, Steenbergen/Lightner)	--	--	N
Assessment of Sperm-Egg Interactions During Fertilization and Hybrid Formation of California Abalones (R/A-39, Vacquier)	--	--	N
Food and Fiber from Seawater, Sand, and Solar Energy (R/A-42, Epstein)	--	--	N
Regulation of the Production of Dormant Cysts by the Brine Shrimp, *Artemia salina*, and Factors Influencing the Viability of Such Cysts (R/A-41, Crowe)	--	--	N
Pathology and Bacteriology of a Disease of Crustaceans Caused by a Marine Bacterium (R/NP-1-9H, Baumann/Bowser)	--	--	N/C
Ova Development Success as a Function of Temperature and Delay in Fertilization Post Spawning (R/NP-1-9L, DeMartini)	--	--	N/C
FISHERIES RESEARCH AND DEVELOPMENT			
The California Market Squid Fishery (R/F-15, Recksiek/Frey)	C	--	--
Optimal Leasing Agreements for Marine Resource Development (R/F-35, Quirk/Lewis)	C	--	--
The Effects of Food Availability on the Growth and Survival of California Jack Mackerel Larvae (R/F-44, Mullin/Lasker)	O	O	C
An Ethnography of the San Pedro Wetfish Fishing Fleet (R/NP-1U, Velez)	C	--	--
Coordinated Management of the Pacific Coast Salmon Fisheries and the Implications of Extended Jurisdiction (R/F-24, R/F-31, Moore et al.)	C	--	--
Protective Immunization of Anadromous Salmonids against *Aeromonas salmonicida* and *Vibrio anguillarum* (R/F-29, Kerstetter)	C	--	--
Development of a Mechanism to Allow Release of Dungeness Crabs from Lost or Abandoned Pots (R/F-27, Jolly)	C	--	--
Endocrinology of Salmon Smoltification and Adaptation to Seawater (R/F-25, Bern)	C	--	--
Comparative Analysis of the Social and Political Systems of the Tuna Fleets of San Diego and Ensenada (R/F-30, D'Andrade/Bailey)	C	--	--
Development of Multispecies Management for Kelp Bed Resources with an Emphasis on Sea Urchins (R/F-36, Tegner)	N	O	O
Improved Marine Food Products and Marine Food Technology (R/F-32, Brown)	N	O	C
Amine Toxicity of Fish Products (R/F-43, Bjeldanes)	N	C	--
Design and Development of a Squid Processing Machine (R/NP-1J, R/F-33, Singh)	N	O	C
Bioconversion of Chitin Wastes (R/F-34, Carroad)	N	O	C
An Economic Study of the U.S. Pacific Albacore Jig Boat Fishery (R/F-38, Holt)	N/C	--	--
Santa Barbara Inshore Partyboat Fishery: Emphasis on the Olive Rockfish (R/F-39, Ebeling)	N/C	--	--
Re-establishment of Anadromous Fishes in Southern California (R/F-42, Van Olst/Ford)	N/C	--	--
A Multispecies Bioeconomic Fisheries Model under Uncertainty (R/F-37, Just)	N/C	--	--
Experimental Abalone Enhancement Program (R/NP-1-7A, Tegner)	N/C	--	--
Limited Entry in the California Abalone Fishery: A Longitudinal Analysis (R/NP-1-7C, Cicin-Sain/Moore)	N/C	--	--
Endocrinology of Normal and Abnormal Salmon Smoltification and Adaptation to Seawater (R/F-45, Bern)	--	N	O
Artificial Imprinting of Chinook Salmon in a Multispecies Hatchery (RF-46, Hassler)	--	N	C
Experimental Abalone Enhancement Program (R/F-47A, Tegner)	--	N	O

Project Title (Project Number, Project Leader)	FY78	FY79	FY80
FISHERIES RESEARCH AND DEVELOPMENT (continued)			
Experimental Abalone Enhancement Program (R/F-47B, Connell)	--	N	C
Sensory and Behavioral Effects of Pollutants on the Crab and Lobster Fishery (R/F-48, Case)	--	N	C
Genetic Improvement of a Chitinase-Producing Microorganism (R/F-50, Ogrydziak)	--	N	C
Coordination of Federal, Regional, and State Policies for Managing Marine Fisheries (R/F-51, Moore/Wyner/Cicin-Sain)	--	N	C
Economics of Fisheries and Aquaculture Development (R/F-52, Johnston/Hand)	--	N	O
An Economic Analysis of the California Abalone Fishery (R/F-53, Deacon)	--	N	O
Economics of Swordfish Vessel Participation and Catch (R/F-54, Holt)	--	N/C	--
Assessment of Aging Techniques and Their Application to Elasmobranch Fisheries (R/F-57, Cailliet)	--	--	N
Multiple Species Utilization of the Herring Eggs-on-Seaweed Fishery (R/F-58, Abbott)	--	--	N
Storage Stability of the Purple-Hinge Rock Scallop, *Hinnites multirugosus* (R/F-59, Josephson)	--	--	N/C
Demographic Analysis of Porpoise Populations Subject to Time-Varying Tuna-Net Mortality (R/F-56, Goodman)	--	--	N
Economics of Multipurpose Fishing Vessels: Assessment and Policy (R/F-61, Holt)	--	--	N
An Economic Analysis of the Gains from Joint Management of Fishery Stocks (R/NP-1-9A, Johnston/Howitt)	--	--	N
Feasibility of Mechanical Skinning of Blue Shark (R/NP-1-9B, Singh/ Katz)	--	--	N/C
Multispecies Aspects of CalCOFI 1955-59 Ichthyoplankton Data: A Source of Information for Variations in California Current Fisheries Resources (R/NP-1-9F, Loeb)	--	--	N
NEW MARINE PRODUCTS			
Antiviral compounds from Algae (R/MP-12, Vedros)	C	--	--
Marine Plants as a Source of Insect Growth Inhibitors (R/MP-14, Crews)	O	O	C
Pharmacological Evaluation Program (R/MP-15, Jacobs)	N	O	C
Marine Natural Products for Pharmacological Evaluation (R/MP-16, Faulkner)	N	O	C
New Agricultural Chemicals from Marine Organisms (R/MP-18, Fenical)	N	O	C
Antileukemia Compounds from the Brown Seaweed *Dictyota* (R/MP-17, Fenical)	N/C	--	--
Neuronal Blocking Substances from California Gobiidae (R/MP-19, Fuhrman)	--	N/C	--
Antiviral Compounds from Algae (R/MP-20, Vedros)	--	N	C
ENERGY			
Stray Electrical Current Hazards to Prestressed Concrete Construction in Seawater (R/E-12, Cornet)	C	--	--
Earthquake Loading on Large Offshore Structures in Deep Water: A Study for the Correlation of Analytic and Physical Models (R/E-14, Wiegel)	O	R	--
Earthquake Loading on Large Offshore Structures--An Application of Experimental Data to Practical Structure Forms (R/E-14, Penzien)	--	R	C
Seismic Hazards to the Development of Offshore Oil Resources (R/E-15, Prothero)	O	C	--
Earthquake Loading on Large Offshore Structures--An Application of Experimental Data to Practical Structure Forms (R/E-14, Penzien)	--	R	C
Seismic Hazards to the Development of Offshore Oil Resources (R/E-15, Prothero)	O	C	--
Power from Salinity Gradients (R/NP-1B, R/E-16, Isaacs)	C	--	--
Studies on Thermophilic Microorganisms Located from Undersea Hot Springs, Electric Power Plant Condensers and Ships' Heat Exchangers (R/NP-1P, R/E-21, Isaacs)	C	--	--
Placement of Underwater Mass Concrete by the Tremie Method (R/NP-1Q, Gerwick)	C	--	--
Marine Vehicle Safety Analysis (R/E-17, Webster)	C	--	--

Project Title (Project Number, Project Leader)	FY78	FY79	FY80
ENERGY (continued)			
Side-Scan Sonar Mapping and Computer-Aided Interpretation of the Geology of the Santa Barbara Channel (R/E-18, Luyendyk/Simonett)	N	O	C
Nearshore Wave Power Source (R/E-19, Seymour)	N/C	--	--
Power Generator Inertially Coupled to Seawaves (R/E-20, Lee/Manalis)	N/C	--	--
A Condensing Turbine for the Distillation of Seawater (R/E-22, Manalis/Lee)	--	N	C
Temperature Tolerances of Benthic Marine Invertebrates and Their Relationship to Regulatory Requirements for Thermal Effluent (R/E-23, Ford/Van Olst)	--	N	C
The Politics and Policy Implications of Deep Seabed Mining: U.S. Options (R/NP-1-8I, Mann)	--	N	O
OCEAN TECHNOLOGY			
Bioelectric Toxicity Assaying (Phase I) (R/NP-1-9M, Anderson)	--	--	N
MARINE AFFAIRS			
A Preliminary Survey of the Impact of Limited Entry Regulations upon California Fishermen (R/NP-1-9K, Petterson/Bailey)	--	--	N/C
A Preliminary Investigation of Indochinese Refugee Adaptation to the Monterey Bay Fishing Industry (R/NP-1-9N, Orbach)	--	--	N
The Deep Seabed Hard Mineral Resources Act: Was There a Need to Precede the Development of International Law Through U.S. Unilateral Action? (R/NP-1-9'O', Lynch)	--	--	N/C
RAPID RESPONSE			
Rapid Response Capability (R/NP-1, Sullivan)	O	O	O

C = Completed Project; N = New Project; O = Ongoing Project;
R = Restructured Project; T = Terminated Project

Activity Budget, 1978-1979

	NOAA Grant Funds	Matching Funds
MARINE RESOURCES DEVELOPMENT		
Aquaculture	$ 439,345	$ 559,522
Living Resources	199,685	199,979
Marine Biomedicinals and Extracts	160,786	80,517
SOCIO-ECONOMIC AND LEGAL STUDIES		
Marine Economics	21,106	10,527
Socio-Political Studies	29,335	9,232
MARINE TECHNOLOGY RESEARCH AND DEVELOPMENT		
Ocean Engineering	118,533	81,314
Resources Recovery and Utilization	64,232	85,871
MARINE ENVIRONMENTAL RESEARCH		
Research and Studies in Direct Support of Coastal Management Decisions	185,013	116,662
Ecosystems Research	90,632	51,531
Pollution Studies	33,271	32,565
MARINE EDUCATION AND TRAINING		
Other Education (Sea Grant Trainees and Interns)	394,095	51,346
ADVISORY SERVICES		
Extension Programs	445,422	266,672
Other Advisory	125,767	105,569
PROGRAM MANAGEMENT AND DEVELOPMENT		
Program Administration	257,779	203,266
Program Development	87,499	44,978
TOTAL	**$2,652,500**	**$1,899,551**

Activity Budget, 1979-1980

	NOAA Grant Funds	Matching Funds
MARINE RESOURCES DEVELOPMENT		
Aquaculture	$425,425	$474,148
Living Resources	259,742	223,450
Mineral Resources	18,403	34,600
Marine Biomedicinals and Extracts	164,456	82,716
SOCIO-ECONOMIC AND LEGAL STUDIES		
Marine Economics	4,420	8,307
Socio-Political Studies	30,564	20,397
MARINE TECHNOLOGY RESEARCH AND DEVELOPMENT		
Ocean Engineering	58,128	59,053
Resources Recovery and Utilization	69,465	66,110
MARINE ENVIRONMENTAL RESEARCH		
Research and Studies in Direct Support of Coastal Management Decisions	182,229	81,049
Ecosystems Research	100,873	70,272
Pollution Studies	39,855	49,056
Environmental Models	26,052	9,342
MARINE EDUCATION AND TRAINING		
College Level	12,038	9,808
Other Education	360,356	50,600
ADVISORY SERVICES		
Extension Programs	495,631	249,555
Other Advisory	158,584	112,292
PROGRAM MANAGEMENT AND DEVELOPMENT		
Program Administration	236,270	200,384
Program Development	197,509	46,546
TOTAL	**$2,840,000**	**$1,847,685**

Matching Funds Sources, 1978-79

Aquarium-Museum Docents	24,534
Counties of: Marin, Sonoma, San Francisco, Santa Barbara, San Mateo, Monterey, San Diego, Ventura, San Luis Obispo	98,390
Donations	54,259
Foundation for Ocean Research	1,047
Humboldt State University	22,058
Kelco	9,170
Marine Colloids	18,000
McMasters University	34,291
San Diego Gas & Electric Co.	21,841
San Diego State University	74,063
San Diego State University Foundation	14,550
San Jose State University	8,807
Soil Control Laboratory	500
Southern California Edison Co.	30,722
Stanford University	14,522
State of California:	
California Resources Agency	392,500
Department of Fish and Game	129,845
University of California	947,014
University of North Carolina	1,438
Zoecon	2,000

Matching Funds Sources, 1979-80

Aquarium-Museum Docents	25,627
Bristol-Meyers	3,930
California Institute of Technology	1,781
Counties: Monterey, San Diego, San Francisco, San Luis Obispo, San Mateo, Santa Barbara and Sonoma	78,449
Donations	71,553
Foundation for Ocean Research	875
Humboldt Bay Fishing Association	300
Humboldt State University	29,758
Humboldt State University Foundation	2,757
Marine Colloids	34,380
San Diego Gas & Electric	25,790
San Diego State University	82,012
San Diego State University Foundation	2,854
San Jose State University/Moss Landing Marine Laboratories	47,939
Stanford University	27,517
State of California:	
California Resources Agency	392,500
Department of Fish and Game	113,293
Union Oil	3,561
University of Arizona	4,634
University of California	895,119
University of North Carolina	3,056

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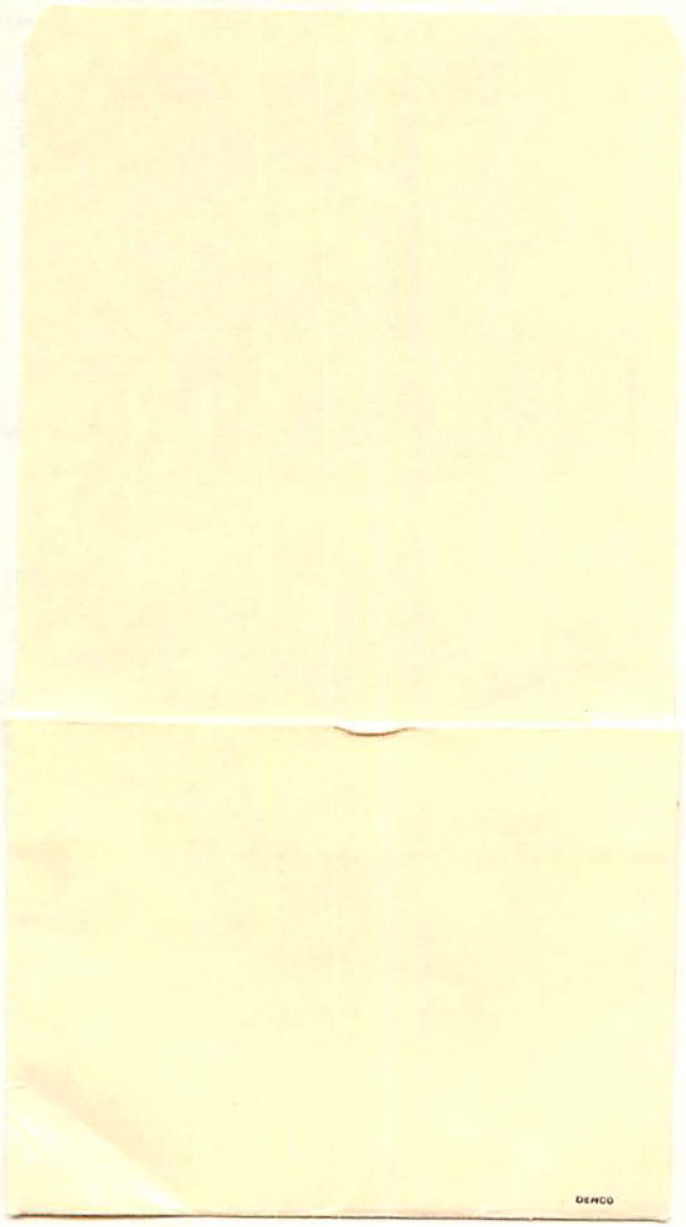
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