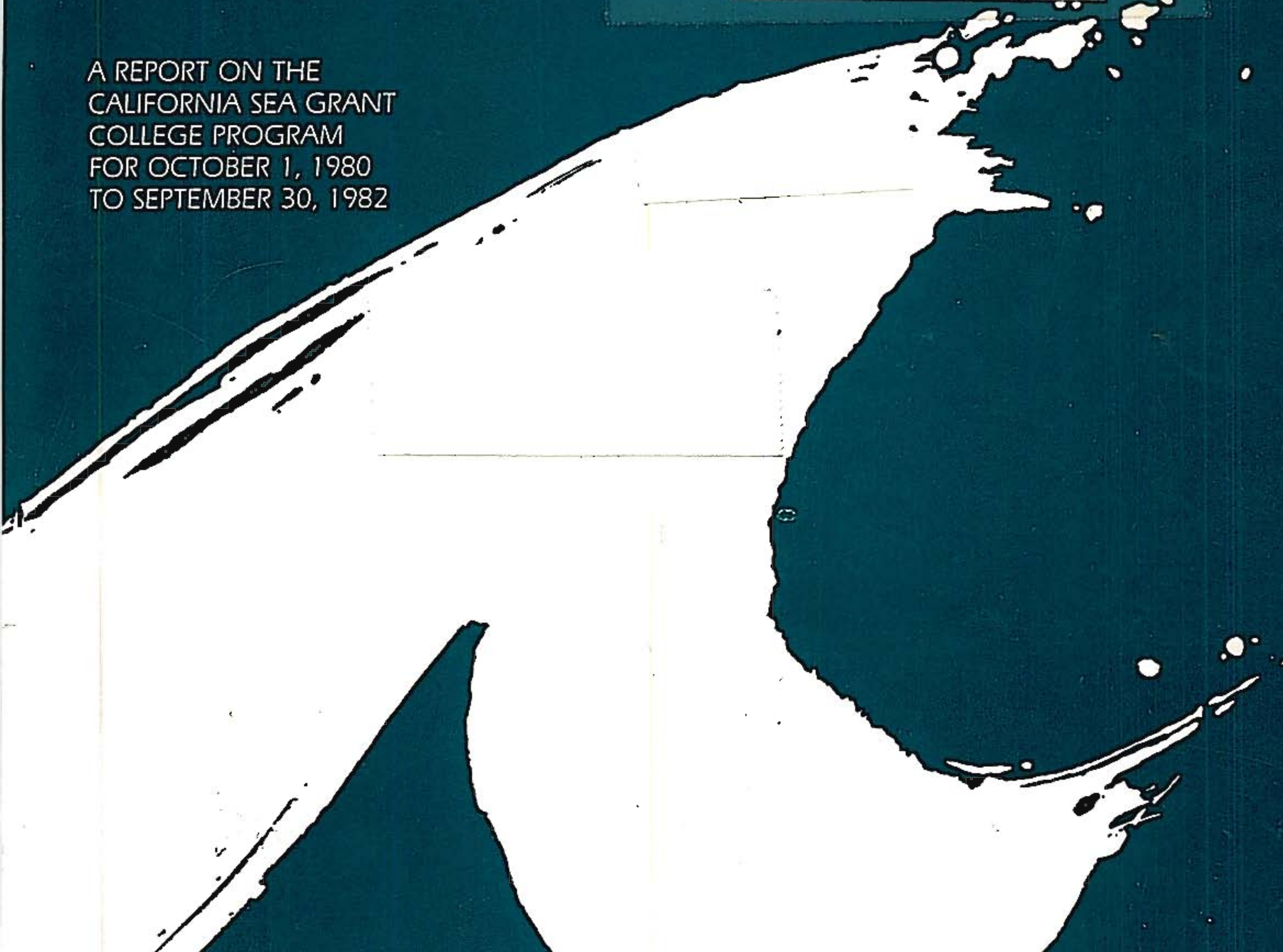
CALIFORNIA SEA GRANT

1980-1982 BIENNIAL REPORT

A REPORT ON THE
CALIFORNIA SEA GRANT
COLLEGE PROGRAM
FOR OCTOBER 1, 1980
TO SEPTEMBER 30, 1982



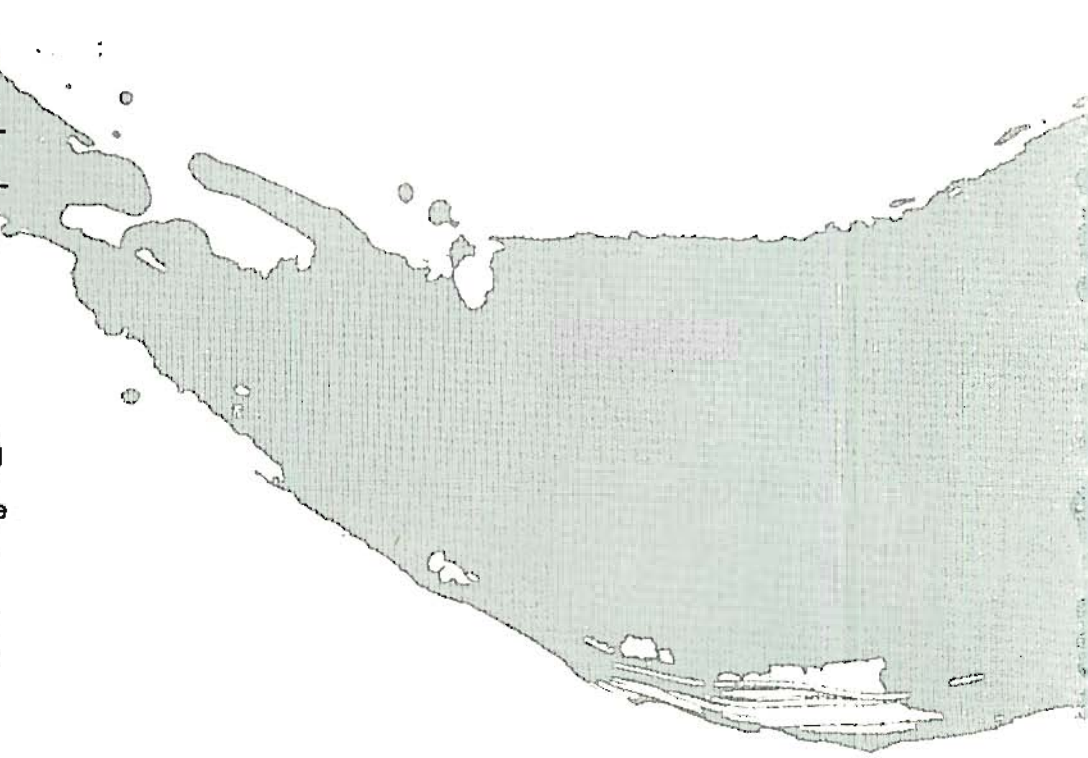
REPORT NO.
R-CSGCP-013

CALIFORNIA
SEA GRANT

Published by the California Sea Grant College Program, Institute of Marine Resources, University of California, La Jolla, 1984. Free copies are available by writing the California Sea Grant College Program, University of California A-032, La Jolla, California 92093.

This work is the result of research sponsored in part by National Sea Grant College Program, NOAA, Department of Commerce, under Grant #NA80AA-D-00120, Project #A/P-1, and all projects through the California Sea Grant College Program, and in part by the California State Resources Agency. The U.S. Government is authorized to produce and distribute reprints for governmental purposes.

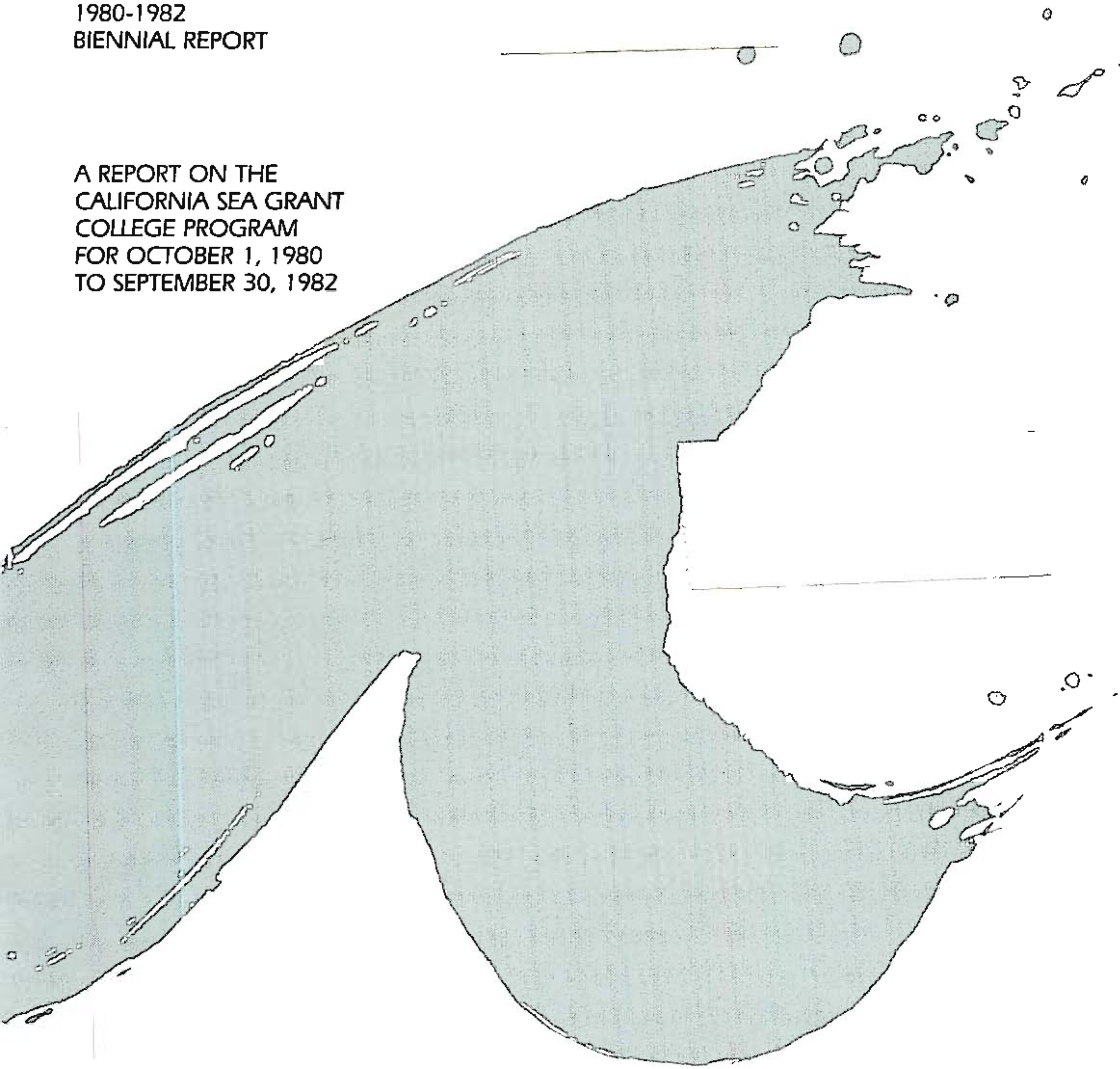
The California Sea Grant College Program is a statewide, multiuniversity program of marine research, advisory services, and education activities administered by the University of California Institute of Marine Resources. Through the research it sponsors, Sea Grant contributes to the growing body of knowledge about our coastal and oceanic resources and helps solve contemporary problems in the marine sphere. Through its Marine Advisory Program, Sea Grant transfers information and technology developed in its research efforts to a wide community of users in California, the Pacific region, and the nation. Sea Grant also supports a range of educational programs for students, teachers, and the general public to promote the wise use of our coastal and oceanic resources by this and future generations.



CALIFORNIA SEA GRANT

1980-1982
BIENNIAL REPORT

A REPORT ON THE
CALIFORNIA SEA GRANT
COLLEGE PROGRAM
FOR OCTOBER 1, 1980
TO SEPTEMBER 30, 1982



REPORT NO.
R-CSGCP-013

INTRODUCTION

This biennial technical report presents the educational, advisory, and research activities undertaken by the California Sea Grant College Program during fiscal years 1980-81 and 1981-82, as required by the National Sea Grant College Program. Unlike its companion volumes, the 1980-81 and 1981-82 summaries, the biennial report presents the accomplishments of our program in the words of the project leaders who conducted the research. The information is not diluted or summarized — it is meant to be a technical record of our accomplishments for use by individuals in academia, government, and industry.

For readers unfamiliar with our program, the California Sea Grant College Program is the largest of 29 Sea Grant programs underway in more than half the nation's states. Its purpose is clearly stated in the 1966 National Sea Grant College and Program Act responsible for its creation: "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."

California's Sea Grant College Program is administered by the University of California Institute of Marine Resources, located at Scripps Institution of Oceanography on the University of California, San Diego campus. Policy guidance comes from the Institute of Marine Resources Advisory Council, appointed by the president of the University of California. The California Sea Grant Committee, composed of representatives from the UC and state university systems and private universities, provides administrative guidance on matters pertaining to the conduct of the Sea Grant program and the pursuit of its objectives. The committee also reviews the program subject areas and appoints independent review panels to assist it in this task.

A seafood industry advisory committee, an aquaculture industry advisory committee, and several other committees help in creating program policy. The Resources Agency Sea Grant Advisory Panel provides valuable program planning and development efforts to help Sea Grant identify and meet state needs.

We hope you find this publication useful, and we welcome your comments and suggestions.

James J. Sullivan
Program Manager

TABLE OF CONTENTS

FISHERIES

NEW MARINE PRODUCTS

MARINE EDUCATION

SEA GRANT TRAINEES

Institute of Marine Resources
E/G-2
1980-82

James J. Sullivan

Associated Staff: William T. Doyle, Richard F. Ford, Robert Holmes, John H. Martin, Bernard Schweigert, Robert Thompson

The major functions of most California universities and colleges are, properly, to provide education and conduct research. The purpose of the Sea Grant Act closely matches the purpose of the University of California — a Sea Grant College — since it calls for education and training, research, and public advisory services. Collegiate research often enhances the educational process: graduate students conduct research under faculty guidance, thus performing significant research and satisfying the educational requirements of a graduate degree.

Many of the research projects conducted by Sea Grant trainees are initiated by the graduate students and supervised by the faculty members who are listed as project leaders. Some trainee projects are portions of larger, faculty-initiated studies that are taken over by a graduate student to become the basis of thesis work. Other trainees work on Sea Grant projects to acquire skills and experience they need to conduct thesis research. Trainees, therefore, are a vital part of Sea Grant's research program; they perform useful applied marine research while acquiring an education.

Progress to Date

Since the first Sea Grant project at UC San Diego in 1968, which developed an interdisciplinary Applied Ocean Science curriculum, graduate students have been heavily involved in Sea Grant's research program. During the first year, 9 graduate students were awarded Sea Grant traineeships. These pioneering trainees were the forerunners of those who have since conducted research with leading California scientists, producing substantive results in such areas as coastal wetland management, aquatic animal reproduction, seaweed mariculture, fishery stock assessments, storage and processing of seafood, marine pharmaceuticals, and assessment and engineering of ocean structures and equipment.

The diverse experience acquired by Sea Grant trainees has helped provide a workforce ready to meet the changing demands for wise utilization of our ocean and coastal resources. Since 1972, at least 95 master's degrees and 92 doctorates have been earned through work related to traineeships. Following their traineeships, most of the graduates secured jobs at universities or in private industry. Most of the individuals who found work in the private sector had master's degrees, while most of those hired by universities had Ph.D.s.

The following highlights from the California Sea Grant College Program show how the knowledge developed under the aegis of the traineeship project is useful in future endeavors.

Sea Grant trainee Wen Gen Liao received his Ph.D. in Civil Engineering at UC Berkeley. As a trainee, Wen Gen conducted research on the effects of earthquake forces on offshore structures. He is currently a project engineer for Interactive Structural Engineering Consultants of San Francisco, and he reports that his present job relates directly to his work as a trainee.

Susan Miller, a graduate with an M.S. in food science and technology, conducted research as a trainee on extending the shelflife of fish using modified atmospheres. Susan writes, "My time spent as a Sea Grant trainee has been a valuable experience in terms of my educational goals. In particular, I had the opportunity to participate in 'hands on' research. This entailed the planning, execution, and completion of those experiments necessary for my thesis project. Upon completion of my degree, I have entered a research-oriented position with Armour. The background I have received as a Sea Grant trainee has amply prepared me for such a position."

Currently a lecturer at San Diego State University, Sandra Slivka completed her trainee research in the area of shrimp immunization. Sandra says the traineeship gave her the opportunity to learn about mariculture and to pursue studies in theoretical and comparative immunology. As a trainee, William Fisher researched bacterial and fungal diseases of externally brooding decapod crustaceans. Today, Bill is a postgraduate researcher in the Environmental Toxicology Department at UC Davis. Robert Fisher received his master's degree in agricultural engineering at UC Davis and is working with Universal Foods Corporation in Greenfield, California.

Stephen Craig Cary received an M.S. for his Sea Grant research on the purple-hinge rock scallop. Craig writes, "The Sea Grant Trainee Program has provided essential and invaluable experience in the field of aquaculture. The program provided not only technical training in many aspects of bivalve hatchery research, but has allowed independent personal growth as a research scientist. The traineeship has supplied all of the data on which my thesis and several recent publications have been based. This past work, and my present research, aided in my recent appointment to the faculty of San Diego State University as an Adjunct Research Associate in the Department of Natural Sciences."

Lisa Levin recently received a Ph.D. in Biological Oceanography from Scripps Institution of Oceanography, UC San Diego, and has accepted a postdoctoral fellowship at Woods Hole Oceanographic Institution. About her traineeship she writes, "My Sea Grant work has allowed me to participate in all phases of the scientific process, including grant preparation, site visits, data collection, data reduction and publication. Through this work, I have broadened my knowledge of marine systems, further developed my skills as a researcher, and have had the opportunity to work with many fine scientists."

Sea Grant trainee Cris Norby is continuing work in the area of coastal wetlands management. He recently completed his thesis on the utilization of estuarine waters as spawning grounds for fishes. He writes, "I have learned the importance of scientist-government interaction in determining wetland management policies. Sea Grant support has allowed me to work closely with a respected researcher in the field of marsh ecology."

Hamidrez Bagheri, a trainee at San Diego State University, completed his master's degree in civil engineering. As a trainee, Hamidrez studied the liquefaction potential of coastal fills. Today he is working with Rick Engineering Company in San Diego. He writes, "My assignment as a Sea Grant trainee provided a unique opportunity for me to study ocean engineering and particularly marine geotechniques. These studies had high educational value for me and would not have been possible without the Sea Grant traineeship."

After earning his Ph.D. in physiological economics, John Lynn is a postdoctoral fellow at the University of Miami. As an applied scientist studying the culture of marine bivalves, Michael Rice completed his master's degree in comparative physiology and has been advanced to Ph.D. candidate. He will take an extended leave to serve with the Peace Corps in the Philippines as an advisor in fisheries biology and shellfish mariculture.

Kurt Shusterick completed his Ph.D. with his dissertation, "The Politics and Policy Implications of Deep Seabed Mining: U.S. Options." He feels his work will become invaluable with the increase in seabed mining activity. Kurt is now a postdoctoral fellow at Woods Hole Oceanographic Institution.

Marcia J. Kooda-Cisco earned her master's degree in biology at UC Riverside for her work in developing procedures for lobster artificial insemination and sperm storage. She now works with the Department of Biology at UC Riverside and writes, "The numerous but nevertheless invaluable techniques learned throughout the course of my study were instrumental in helping me obtain a professional career in scientific research. Therein lies the value of the Sea Grant traineeship as an educational tool."

JOHN D. ISAACS MEMORIAL SCHOLARSHIP

James J. Sullivan and Dale Ingmanson

Until the John D. Isaacs Memorial Scholarship was established in 1981, there were no prizes or fellowships available to recognize unique, creative science fair projects in the broad area of marine related studies.

The scholarship is sponsored by the California Sea Grant College Program to honor the memory of Professor John D. Isaacs, a monumental figure in marine research. Nominally, he was Professor of Oceanography at Scripps Institution of Oceanography and Director of the University of California's Institute of Marine Resources. But he was much more than a professor and administrator.

John Isaacs was full of energy, enthusiasm, and unfettered imagination. He devoted most of his adult life to unravelling the mysteries of the ocean and sharing his knowledge through his books, courses, and inventions. His research interests ranged widely, from deep ocean ecology to climate studies and from developing ocean energy sources to designing satellites.

Professor Isaacs will always be remembered for his unique ability to ask the right questions, as well as his use of parables and stories to make complex topics easier to understand. His attitudes were reflected in his favorite expression, which was "When I meet the maker of the universe, I would like to be able to tell him a little of how it works."

The John D. Isaacs Memorial Scholarship was established to recognize excellence in research by a high school senior who exhibits those characteristics most admired in John D. Isaacs and to encourage interest in marine science education at the high school level.

The California Sea Grant College Program supports high quality applied marine research and with the establishment of the John D. Isaacs Memorial Scholarship, hopes to encourage high school scholars to pursue higher education in marine studies.

The scholarship was awarded for the first time in 1981 to Amy Kimball for her project, "The Ecological Aspects of an Intertidal Limpet." Amy, a graduate of Point Loma High School, is presently attending the University of California at Santa Cruz.

In a recent letter to the California Sea Grant Program Office, she wrote...

> "...I will begin working with a graduate student who will teach me histological techniques. She is working with a very small clam, trying to learn its reproductive behavior. I am pleased that she can use my help; this is a perfect way to learn histology."

According to Kimball, the Sea Grant-sponsored Isaacs Scholarship was the only one of its kind available to her as a graduating high school senior. "There were some general science fellowships available," she said, "but none specifically for marine science except the Isaacs Scholarship."

John David Wikert won the 1982 scholarship for his project on developmental and structural differences among species of nudibranchs, or sea slugs. Hoping to dispel the "slimy slug" image of nudibranchs, Wikert displayed many nudibranch species in a 10-gallon seawater aquarium and prepared a report on the ways these unusual creatures defend themselves. Wikert is currently majoring in aquatic biology at the University of California, Santa Barbara.

Any high school senior in California is eligible to receive the scholarship. The student must enter a Regional and/or County Science Fair and be advanced to the California State Science Fair. A selection committee will be made up of five people appointed annually by the California Sea Grant College Program Manager. The award will be given to the California college or university chosen by the student, and will be passed on to the student by the university in monthly increments during four college years. At the end of each academic year, the recipient will submit a progress report and will receive continued support provided that he or she makes reasonable progress toward the bachelor's degree and remains committed to marine-related studies. The award will be coordinated through the California State Science Fair and will be awarded only in those years when the selection committee decides that a worthy candidate has been identified.

The selection committee will determine that the awardee has

1. a unique, creative marine-related science fair project in the California State Science Fair
2. been accepted at and will attend a California college or university
3. a number of those characteristics (originality, curiosity, depth of intellect, etc.) that were most admired in John D. Isaacs.

The John D. Isaacs Memorial Scholarship consists of an award of $10,000 with an annual stipend of $2,500 per year for 4 years, to a student who will attend a college or university in California. The award is intended to recognize excellence in research by a high school senior and to encourage further pursuit of excellence in higher education in California by the student.

MARINE ADVISORY PROGRAM

University of California, Davis
A/EA-1
1980-82

Robert J. Price

The continuing goals of the Marine Advisory Program are to promote the sound development, management, and use of California's marine resources; to identify California marine resource audiences and their needs; to provide technical information and assistance to those involved in managing, developing, and utilizing the state's marine resources; to improve communication and cooperation among marine resource audiences, and between these audiences and researchers; to actively encourage and speed the adoption of new technologies generated from university and nonuniversity research information; to identify needs and opportunities for future Sea Grant research, and effectively communicate these needs to the academic community; and to develop and improve Marine Advisory Program staff capabilities to accomplish these goals.

Two vacant marine advisor positions, one in the San Francisco Bay Area and one in Los Angeles and Orange counties, will be filled during 1982. A proposed new position in the Ventura County-northern Los Angeles County area will remain unfilled for an indefinite period due to budgetary constraints. Advisory services for these areas are currently handled by marine advisors and specialists from nearby areas. Marine Resources Specialist Christopher Dewees was redesignated as Marine Fisheries Specialist in September 1981. This reassignment reflected changes in overall Marine Advisory Program priorities and expanded Christopher Dewees' role in coordinating advisory activities in the San Francisco Bay area.

Two statewide and six local newsletters were prepared and distributed by specialists and advisors on a monthly or quarterly basis. These newsletters provided current and pertinent information on Marine Advisory Program activities and on other marine-related topics. Special publications on specific topics were also prepared in response to the expressed needs of clientele. A variety of workshops, short courses, and training sessions were held, and these continue to be our major means of encouraging the adoption of new technologies. Individual contacts between specialists and advisors and their constituencies continue to be an important mechanism for providing technical assistance to marine resource audiences and for applying Sea Grant knowledge where it is needed.

Workshops and training sessions in fisheries were conducted along the entire California coast and were attended by about 3,000 fishermen. A series of workshops designed to assist salmon fishermen in improving their efficiency was attended by about 1,000 commercial fishermen. These fishermen learned how lure speed, currents, and water temperature affect catch rates and used this information to improve fishing efficiency. Additional workshops were held on Pacific whiting utilization, abalone fishery enhancement, fisheries management, hydraulics, trawling and other gear development subjects, salmon stream enhancement, refrigeration, antitrust laws, fisheries economics, federal assistance programs, and forming cooperatives. Workshops on alternative fisheries such as shark, octopus, scallops, sea cucumbers, sablefish, Pacific whiting, rockfish, squid, and rock crab enabled fishermen to generate off-season income. Following these workshops, several vessels began longlining for shark in San Francisco Bay and landed over $10,000 worth of shark. Other fishermen are currently experimenting with octopus gear.

In cooperation with NMFS, NESS, JPL, NASA/Ames, and Scripps Institution of Oceanography, Marine Advisory Program staff conducted workshops on the effective use of satellite remote sensing temperature and ocean color charts to conserve fuel and searching time in locating fishing grounds. In northern California, the marine advisor worked with a local television station to adapt these charts for television. Fishermen in northern California and southern Oregon can now trace charts from their television screen before leaving port in the morning, or can pick up the station within 30 miles of major cities if they have televisions on board their vessels. Estimates have shown that west coast salmon and albacore fishermen could save $500,000 yearly in fuel by using remote sensing data to locate fishing grounds.

Marine Advisory Program research projects have provided valuable information to the seafood industry, sports fishermen, and consumers. A feasibility study of the onboard mechanical skinning of blue shark, and a West Coast Fisheries Development Foundation-funded project to develop a blue shark fishery in southern California were completed. The shark skinning study showed that while the technology is available to design a marketable skinning machine, the device would not be economically viable until a larger market for the blue shark is developed. The blue shark fishery project resulted in further development of southern California's blue shark fishery and increased sales of blue shark in the area. Marine advisory staff will continue to work with the fishing industry in California and other Pacific coast states to further develop shark fisheries.

A project to develop Pacific whiting products and markets is continuing and, if successful, could expand our domestic Pacific whiting fishery. This project has led to an expanded Pacific whiting fishery in northern California and Oregon where several trawlers are currently supplementing their traditional deliveries of dragfish with dressed Pacific whiting. Projects on salmon stream enhancement have attracted public attention and support throughout northern California. Marine Advisory Program technical assistance in a San Francisco Bay salmon enhancement project has resulted in increased sport and commercial catches during the 1980 and 1981 seasons. Over 1,000 king salmon released in 1977 were harvested with a market value of over $50,000.

Refrigeration workshops held in 1982 spawned a research project on the effectiveness of the new barrel systems for holding salmon at sea. In cooperation with commercial fishermen and seafood processors, Marine Advisory Program staff investigated the effects of using chilled fresh water, chilled diluted seawater, and ice on salmon quality and shelf life. The results of this project will be used to develop recommendations to improve salmon quality.

A research project started in 1980 to design and develop an air-powered fish processing knife is nearing completion. A prototype knife, developed in cooperation with Ghio Seafood Products and the Food Science and Technology Department, has been successfully tested under commercial conditions. A record of invention for the knife has been filed with the University of California.

Group meetings, publications, and individual contacts have assisted in resolving conflicts involving multiple uses of marine resources. Meetings between commercial fishermen and oil industry representatives have improved communications between these groups and have resulted in progress toward resolving conflicts involving seismic survey vessels, bottom obstructions, and underwater pipelines. These efforts have resulted in the removal or identification of all abandoned submerged wellheads (under federal jurisdiction) in the Santa Barbara Channel. A publication, in seven Asian languages, on California Tide Pool Regulations and a publication in Vietnamese summarizing commercial fishing regulations have been successful in minimizing conflicts between Asian immigrants and commercial and sports fishermen. A forum entitled "Management of Sea Otters and Shellfish Fisheries in California" attracted over 300 people and provided the opportunity for groups with divergent views to discuss management issues in a nonthreatening atmosphere. Although the sea otter-shellfish conflict was not resolved, the forum did serve to improve communications among the various groups and to point out the difficult decisions that marine resource managers must make in resolving this conflict under existing federal laws.

Seafood technology workshops and short courses included six food canning short courses, six sanitation workshops, three food microbiology short courses, two aquaculture processing workshops, and additional workshops on salmon quality, marine refrigeration, sensory evaluation, quality management, and Pacific whiting marketing. Individual processors were assisted with waste management, quality control, and product development problems and in developing in-house training materials. Data from research projects on Pacific whiting product development, modified atmosphere storage of seafood, and water conservation in Pacific shrimp processing was provided through group meetings and newsletter items.

A variety of seafood processing companies, including Van Camp Seafood Co., Far West Services, Inc., California Sunshine, Inc., Pt. St. George Fisheries, and Schnaubelt Fisheries, have used information provided on sanitation and quality control to develop their own in-house training programs. Schnaubelt Fisheries, Machado Fisheries, and others have adapted processing waste utilization processes provided by our program. Tarantino Fish Co., Race Street Fish and Poultry, Schnaubelt Fisheries, Tom Lazio Fish Company, and others have used information provided on modified-atmosphere packaging and continue to seek advice and information on new packaging and processing methods. Meredith Fish Company, Eureka Fisheries, Pt. St. George Fisheries, Ghio Seafood Products, Sushi Seafoods, and others have used research data from projects on water conservation, processing techniques, shark jerky, and seafood marketing.

Information and technical assistance provided by the Marine Advisory Program to Crescent City enabled the city to obtain a permit from the state of California to discharge screened seafood processing waste water directly into the ocean. This is the first permit for direct ocean discharge of seafood wastes granted in California. Sewage discharge costs for most Crescent City seafood processors have dropped from an average of about $1,200 a month to $500-800 a month. In 7-10 years, after the project is paid for, discharge rates will be further reduced.

Information on the Marine Advisory Program and on current seafood research projects was prepared and distributed to over 900 licensed seafood processors in California. Information and assistance were given to the Department of Health Services and the seafood industry to publicize, explain, and limit the effects of the 1980 paralytic shellfish poisoning outbreak. News releases and an updated publication entitled "Paralytic Shellfish Poisoning and Red Tides" were prepared and distributed throughout the state. Information on home seafood processing and on seafood safety and nutrition was provided to home economists, food editors, and consumers through numerous consumer seafood workshops, news releases, and personal contacts.

A research forum on ports and transportation was held, and the proceedings were written and distributed. The Ports and Transportation forum proceedings have been used by researchers and state agencies to identify and address the research needs in port and harbor management and marine transportation. A survey of wood piling performance was conducted to identify and characterize dock deterioration from weathering and marine borers. Port and harbor districts were provided with information on dock piling specifications and maintenance programs to minimize major dock deterioration. Through group meetings and individual contacts, port and harbor districts were given information on seafood handling and processing facility needs, harbor expansion planning, projected vessel berthing needs, and commercial marine fisheries.

Educational information and assistance were provided to the California Coastal Commission, regional coastal commissions, and to local coastal planners on fishery- and aquaculture-related coastal problems. Information was also provided to these groups on harbor planning, coastal recreational access, offshore oil drilling, wetlands management, commercial and recreational fisheries, and marine aquaculture.

County planning departments and coastal commissions have used this information to develop local coastal plans. The Port of Los Angeles, Dana Point Harbor, Ventura Harbor, Santa Cruz Harbor, the Port of Oakland, the Port of San Francisco, and Crescent City Harbor are examples of the many ports and harbors which have requested and received assistance in planning future commercial fishing facilities.

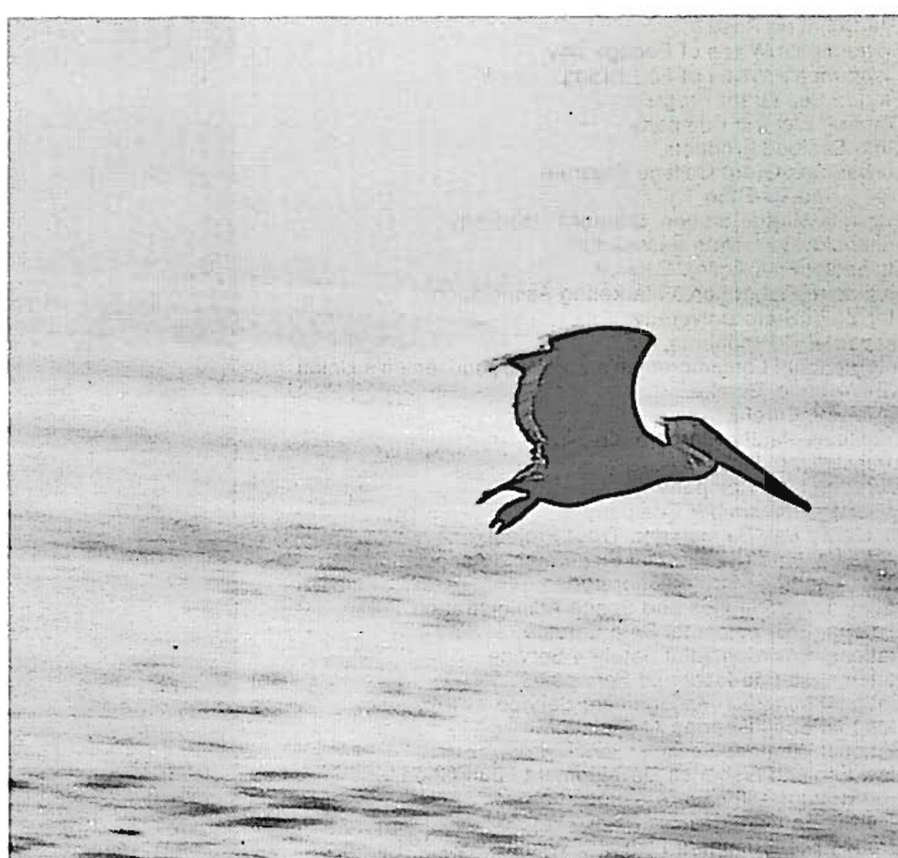
The California marine aquaculture industry was assisted in developing the West Coast Aquaculture Foundation, and in uniting the entire aquaculture industry under the California Aquaculture Association. University research in oyster genetics and marine pathology has been initiated, resulting from the establishment and recommendations of an advisory program-industry-university advisory committee. A disease diagnostic service for the marine aquaculture industry was organized. The oyster industry was assisted in obtaining information on National Marine Fisheries Service and U.S. Department of Agriculture disaster relief loans during and following the 1980 paralytic shellfish poisoning outbreak. A publication on aquaculture in the coastal zone was revised and reprinted to provide needed and current information to coastal planners, and an overview paper entitled "The California Oyster Industry" was prepared and presented at the National Oyster Workshop and will be published next year. Through group meetings, newsletters, and individual contacts, information on shellfish depuration, aquaculture production and marketing, disease prevention, industry grant programs, aquacultural research, and aquaculture feasibility was provided to the industry and to prospective aquaculturists.

Aquaculture operations have used Marine Advisory Program information in developing and monitoring production facilities and in developing and marketing aquaculture products. With our assistance, Pacific Ocean (abalone) Farms submitted a proposal for, and was awarded, a National Science Foundation-industry grant, and a Small Business Administration marketing study for the shellfish industry was completed. Meetings were held with the aquaculture industry and the California Department of Fish and Game to propose and review changes in Title 14 regulations affecting the marine aquaculture industry.

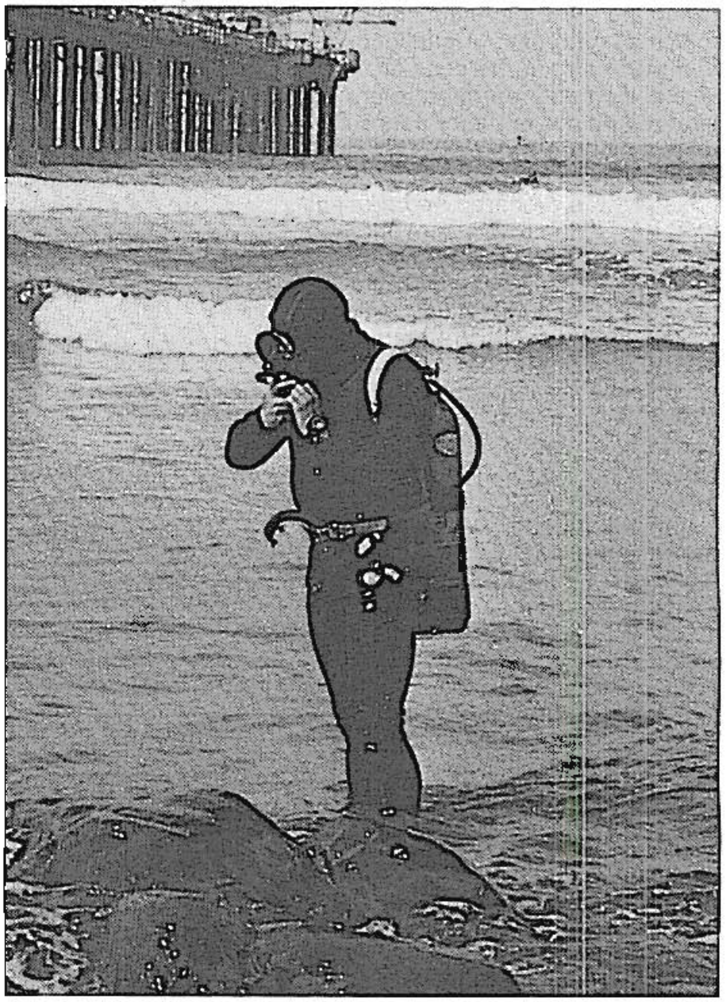
Marine educational activities included a diversified program ranging from assisting in the development of formal university-level marine science curriculum to radio and television consumer-education programs. Methods used to extend this information included career days, news releases, radio and television programs, class talks, training sessions, and mobile outreach projects. A 4-H Leaders' Guide in marine education was completed in 1981, and a proposal was submitted to the San Francisco Foundation to do an in-depth marine education pilot project in Marin County. In several counties, 4-H groups were assisted in starting marine science clubs and in developing marine education displays. A Mobile Marine Science Outreach project was initiated at California State University, Long Beach with our assistance and has been extremely popular and successful in southern California. A publication on recognizing, treating, and preventing salmon poisoning in dogs was completed.

An experimental vocational education program was initiated in 1981 for fishermen in San Luis Obispo County. This program, developed in cooperation with Cuesta College and the local Commercial Fishermen's Association, provides self-learning opportunities for anyone needing technical marine information.

The Marine Advisory Program continues to be regarded as an excellent source of unbiased technical information and assistance on marine resource topics. Requests for information and assistance are received from a broad spectrum of marine audiences including consumers; sports fishermen; port and harbor managers; seafood processors, wholesalers, and dealers; aquaculture firms; commercial fishermen; environmentalists; local, state, and federal regulatory and service agencies; oil and gas companies; educational institutions; investors; and home economists. The Marine Advisory Program provides a useful and needed service, directly or indirectly, to the entire population of California.



Cooperating Organizations
Alaska Sea Grant College Program
American Fisheries Society
Bodega Bay Fishermen's Marketing Association
Burnt Hill Salmon Ranch
Cal Poly San Luis Obispo
California State University, Long Beach
California Aquaculture Association
California Association of Harbormasters and Port Captains
California Association of Port Authorities
California State 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 Farm Bureau
California Fisheries Association
California Institute of Technology
California Maritime Academy
California State and Regional Water Quality Control Boards
California Seafood Institute
California Shellfish Company
California State Lands Commission
Catfish Farmers of America
Commercial and Sport Fishermen
Commercial Fishermen's Wives of Humboldt
Counties of Del Norte, Humboldt, Mendocino, Sonoma, Marin, San Francisco, San Mateo, Santa Cruz, Monterey, San Luis Obispo, Santa Barbara, Ventura, Los Angeles, Orange, and San Diego
Crescent City Harbor Commission
Crown-Simpson Pulp Company
Cybertext Corporation
Del Norte Fishermen's Marketing Association
Del Norte School District
Eureka Fisheries
Eureka Ice and Cold Storage
F/V Colintino Rose II
Fishermen's Wives of Bodega Bay
Fishermen's Wives of Fort Bragg
Florida Sea Grant Program
General Electric Company
Ghio Seafood Products
Hawaii Sea Grant College Program
Hoopa Indian Tribe
Hopkins Marine Station, Stanford University
Humboldt Bay Pilots Association
Humboldt Fish Action Council
Humboldt Fishermen's Marketing Association
Humboldt State University
Industrial Components, Inc.
International Longshoremen's and Warehousemen's Union
KEKA-Radio, Eureka
KIEM-TV, Eureka
Louisiana-Pacific Corporation
Luhr-Jensen, Inc.
Meredith Fish Company
Miller-Rellim Lumber Company
Monterey Bay Salmon and Trout Project
Moss Landing Commercial Fishermen's Association
Moss Landing Marine Laboratories
National Aeronautics and Space Administration
National Environmental Data Service
National Environmental Satellite Service
National Marine Fisheries Service
National Minerals Management Service
National Shellfisheries Association
National Weather Service
New England Fisheries Development Foundation
Northwest Steelheaders Association
Noyo Pride Fisheries
Oregon Department of Fish and Wildlife
Oregon Sea Grant College Program



Pacific Coast Federation of Fishermen's Associations
Point St. George Fisheries
Port of Oakland
Port of San Francisco
Prairie Creek Fish Hatchery
Producers Seafood
Quality Refrigeration
Rek-Wor Indian Community Association
Rowdy Creek Fish Hatchery
Salmon Unlimited
San Diego State University
San Francisco Tyee Club
San Jose State University
Santa Barbara Museum of Natural History
Smith River Alliance
Smith River Anglers Association
Smith River Kiwanis Club
Soil Conservation Service
Star Shipping
United Indian Development Association
University of California, Berkeley
University of California, Bodega Marine Laboratory
University of California, Cooperative Extension
University of California, Davis
University of California, Division of Agricultural Sciences
University of California, Irvine
University of California, Los Angeles
University of California, San Diego
University of California, Santa Barbara
University of California, Santa Cruz
University of California, Scripps Institution of Oceanography
University of Southern California
U.S. Bureau of Land Management
U.S. Coast Guard
U.S. Corps of Engineers
U.S. Fish and Wildlife Service
U.S. Forest Service
U.S. Geological Survey
U.S. Trout Farmers Association
Washington Sea Grant College Program
West Coast Aquaculture Foundation
West Coast Fisheries Development Foundation
Westfall Stevedore Company
Western Oil and Gas Association

Publications

ARNOLD, S. H., PRICE, R. J., AND BROWN, W. D. 1980. Histamine formation by bacteria isolated from skipjack tuna (*Katsumonus pelamis*). Bull. Jap. Soc. Sci. Fish. 46:991-995.

BROWN, D. E., SINGH, R. P., GARRETT, R. E., AND KATZ, B. 1981. Physical properties of blue shark useful in designing a skinning machine. Marine Fisheries Review 43:15-22.

BROWN, D. E., SINGH, R. P., GARRETT, R. E., AND KATZ, B. A. 1980. Feasibility of mechanical skinning of blue shark. A final project report to Sea Grant College Program.

BROWN, W. D., ALBRIGHT, M., WATTS, D. A., HEYER, B., SPRUCE, B., AND PRICE, R. J. 1980. Modified atmosphere storage of rockfish (*Sebastes miniatus*) and silver salmon (*Oncorhynchus kisutch*). J. Food Sci. 45:93-96.

BYBEE, J. R. AND RICHARDS, J. B. 1979. An assessment of commercial fishing facilities and the potential for commercial fishing industry expansion in Santa Barbara and Ventura County Harbors. NOAA Technical Memorandum NMFS-F/SWR-001.

CICIN-SAIN, B., GRIFMAN, P. M., AND RICHARDS, J. B. 1982. Social science perspectives on managing conflicts between marine mammals and fisheries. Marine Science Institute, University of California at Santa Barbara and University of California Cooperative Extension.

CONTE, F. S. In press. 1982. Aquaculture: an international prospective, and opportunities for growth in Pacific states. In *Proceedings of the Big Island Aquaculture Conference*. Hilo, Hawaii.

CONTE, F. S. In press. 1982. California aquaculture. In *A guidebook to California agriculture*.

CONTE, F. S. AND DUPUY, J. L. 1981. The California oyster industry. J. World Mariculture Soc.

CONTE, F. S. AND GARRETT, R. C. 1982. Conversion factors for aquaculture and fisheries. Leaflet 21291. Division of Agricultural Sciences, University of California.

Conte, F. S. and Manus, A. T. 1980. Aquaculture and coastal zone planning. California Sea Grant College Program.
Conte, F. S. and Manus, A. T. 1982. Aquaculture and coastal zone planning. California Sea Grant College Program. (Revision).
Dewees, C. M. 1980. The sablefish fishery. Leaflet 21155. Division of Agricultural Sciences, University of California.
Dewees, C. M. 1982. Guidelines for marine ecological surveys-nekton. California Sea Grant College Program.
Dewees, C. M., Hilgeman, C., Campodonico, E., and Marshall, C. 1982. 4-H Marine science leaders manual. Leaflet 4-H-7016. Division of Agricultural Sciences, University of California.
Dewees, C. M. and Price, R. J. 1982. Overview of the squid fishery on the Pacific coast of the United States. In *Proceedings of the International Squid Symposium.* UNIPUB, New York. pp. 197-221.
Doroshov, S., Conte, F., and Clark, W. 1979. Aquaculture of animal species. In *The biosaline concept,* A. Hollaender *et al.*, eds. Plenum Press, New York.
Garoyan, L. and Taylor, S. 1980. Forming a fisheries association. Leaflet 21210. Division of Agricultural Sciences, University of California.
Katz, B. 1980. In *Proceedings of the forum for marine transportation and port management and develoment,* B. Katz, ed. California Sea Grant College Program.
Katz, B. A. and Martin, H. 1981. Commercial fishing laws (Vietnamese translation). California Sea Grant College Program.
Price, R. J. 1980. In *The management of quality,* R. J. Price, ed. Institute of food technologists, Chicago.
Price, R. J. 1980. Equipment for microbiological quality control. Monograph. Cooperative Extension, University of California.
Price, R. J. 1981. Seafood myths and misconceptions. Hornblower 34:8-9.
Price, R. J. 1982. Paralytic shellfish poisoning and red tides. Leaflet 21117. Division of Agricultural Sciences, University of California. (Revised).
Price, R. J. and York, G. K. 1980. Smoking fish at home. Leaflet 2669. Division of Agricultural Sciences, University of California.
Ray, D., Fodge, B., and Toole, C. 1982. Is there a role for the coastal commission in coordinating commercial fisheries development. In *Proceedings of the California Coastal Commission Ocean Study Symposium.* (Accepted for publication).
Richards, J. R. 1982. Directory of agencies and agency personnel providing assistance with offshore oil development/fisheries problems. Santa Barbara County Marine Advisory Program/Cooperative Extension.
Richards, J. R. 1982. Summary of proposed offshore exploratory drilling projects. Santa Barbara County Marine Advisory Program/Cooperative Extension.
Toole, C. 1982. Where do the numbers come from?: answers to five questions about salmon management in northern California. Humboldt County Marine Advisory Program Bulletin.
Waldvogel, J. 1981. Statistical analysis of adult chinook salmon spawned at Rowdy Creek fish hatchery (1980). California Sea Grant Marine Advisory Program.
Waldvogel, J. B. 1982. Socio-economic analysis of Brookings, Oregon salmon ocean sportsfishery. Del Norte County Marine Advisory Probram bulletin.
Waldvogel, J. B. 1982. Socio-economic analysis of Crescent City salmon ocean sportsfishery. Del Norte County Marine Advisory Program bulletin.
Waldvogel, J. B. and Blatteis, G. 1979. Marine Algae. Leaflet 21110. Division of Agricultural Sciences, University of California.
Waldvogel, J. B., Dewees, C. M., Loomis, E. C., and Douglas, L. R. 1982. Protecting your dog from diseases caused by eating raw fish. Leaflet 21318. Division of Agricultural Sciences, University of California.

COMMUNICATIONS, PUBLICATIONS, AND PUBLIC ADVISORY SERVICES

James J. Sullivan

Associated Staff: Kelly E. Anderson

Sea Grant has access to a wealth of information that concerns the nation's ocean and coastal resources. Because this information could affect decisionmaking in the use, management, and development of our resources, Sea Grant must disseminate the results of its research to a variety of concerned groups in government, the scientific community, industry, the general public, and Sea Grant's statewide and national programs.

To accomplish effective information dissemination, the communications office performs a variety of services, including:

- writing and publishing Sea Grant project results in technical, reference, and educational publications aimed at a variety of audiences;
- distributing the books, reprints, technical reports, and announcements produced or sponsored by the Sea Grant program;
- advising program investigators, administrators, and advisory personnel about effective techniques for communicating with user groups, the scientific community, and the general public;
- providing the public with information about Sea Grant's projects, services, products, and activities.

The overall project objective is to disseminate research information to an ever-growing network of academicians, government and elected officials, ocean user groups, and the general public to improve the understanding of and decisionmaking concerning the wise use of coastal and ocean resources.

Improving and broadening our existing information dissemination system required a number of internal and external changes in 1980-81, which resulted after a lengthy examination and evaluation of publications policy, program staff and equipment, current and potential audiences, information markets, and special interest needs.

The major goals for 1980-81 were 1) to assess and expand the scope of communications activities, 2) to support and develop the publications program, 3) to distribute several publications, including a technical biennial report and a popular summary of it, 4) to consolidate and expand an in-office distribution mailing list system, and 5) to expand the new computer-based information management system. Significant progress was made in all of these areas.

The position of communications coordinator, established in August 1979, was evaluated and redefined to emphasize the need for greater participation in liaison activities with the National Sea Grant College Program, other state and Sea Grant programs, state and local government agencies and committees, university public information offices, the Marine Advisory Program, and project leaders.

Communications activities were expanded to include the above groups more directly, with the communications coordinator primarily responsible for initiating and maintaining an open communications network between the California Sea Grant College Program (CSGCP) and these groups.

Support and development of the publications program was accomplished by instituting the publications policies developed in 1980 and by defining three new publication series for technical, educational, and reference publications.

Several publications were produced and distributed in 1980-81, including the California Sea Grant publications policy, the program's first biennial technical report, and the 1980-81 program summary. Other particularly noteworthy publications produced and distributed include the first publication in our technical publication series: *The Suitablity of the Purple-Hinge Rock Scallop to Marine Aquaculture*; the first publication in our educational series, a filmstrip-tape package with written narrative: "Palau's Marine Ecosystems"; and the third publication in our reference series: *Directory of Academic Marine Science Programs in California: Community Colleges, Four-Year Colleges, and Universities.*

The directory is especially important to Sea Grant's goal to support development of marine education and training. It is the only volume of its kind that provides comprehensive information about marine academic programs available at California's colleges and universities, and it is a particularly valuable reference tool to help students select a college and plan an academic program with a marine focus. More than 1000 copies of the directory have been sent to California high school guidance counselors and libraries, marine science teachers and professors, and members of the general public who have expressed an interest in our marine education publications.

In addition, copies of 46 reprints, reports, and proceedings resulting from Sea Grant-funded projects were distributed by the California Sea Grant College Program office in 1980-81.

In 1980-81 more than 21,000 copies of publications were distributed to members of the following groups according to their specified area of interest:

State assembly members and staff
State senate members and staff
U.S. representatives and staff
U.S. senators and staff

Local, state, and federal agencies

Sea Grant network
directors

communicators
marine advisory leaders
project leaders
trainees

University
public affairs offices
administrative officials
regents

Educational leaders at
elementary schools
high schools
colleges and universities

Industry officials
Nonprofit organizational heads
The news media
The general public

The above groups have received California Sea Grant publications and activity announcements in the areas of aquaculture, fisheries, technology, nonliving resources, energy, education, seafood, chemistry, toxicology, mammals, recreation, ecology, man in the sea, ports and harbors, transportation, wetlands, marine flora, and marine legislation.

In 1981 we received 4,000 more publication requests than we did in 1980, an increase of 41%. The majority of these requests (43%) came from the educational community, which includes universities and colleges, public schools, libraries, and students. The general public requested 32% of our publications; local, state, federal, and special interest agencies requested 15%; and commercial interests — including industries, fishermen, and seafood processors — accounted for 10% of the publications requests.

In 1981-82 we continued to work towards our 1980-81 goals and added the following new goals: 1) to expand the range and variety of communications activities, 2) to promote Sea Grant research results and accomplishments to a broader variety of audiences, 3) to improve the general public's awareness and understanding of Sea Grant program activities locally, regionally, and nationally, 4) to improve the international dissemination of key technical publications, 5) to distribute several publications, including three new books in the technical series, the annual summary, and the program directory, 6) to cut costs associated with the production of standard publications, without sacrificing quality.

In 1981-82 we were involved in a broader range of activities to increase the regional, national, and international visibility and dissemination of California Sea Grant research results and accomplishments. During the year, the communications staff improved program visibility and product dissemination by representing California Sea Grant research results and accomplishments at more than 20 local, state, regional, and national meetings sponsored by universities, industries, government organizations, and private associations. A partial list of events during which California Sea Grant program products were presented is provided below.

Local

Hopkins Marine Station (Stanford University) Open House
Center for Coastal Marine Studies (UCSC) Open House
Scripps Institution of Oceanography (UCSD) Public Affairs press conferences

State/Regional

California Aquaculture Association Conference
California Coastal Commission Ocean Study Project
California Museum of Science and Industry "MUSE's Marine and Biological Sciences/Engineering Symposium"
Sacramento County Office of Education, Environmental Education Week
California Seafood Institute Convention
Southwest Marine Education Conference
Tiburon Center for Environmental Studies Wetlands Workshop
Aquaculture in San Francisco Bay Workshop

National

Gulf and Caribbean Fisheries Institute
Fish Expo '82
Coastal Zone 7
Oceans '82
Third Annual Big Island Aquaculture Conference
Sea Grant Week

The communications staff also provided information and assistance in support of the following events and programs:

Marine Mammals Symposium (sponsored by the Scripps Institution of Oceanography Aquarium)
Boating Safety Classes (sponsored by the California State Resources Agency, Dept. of Boating and Waterways)
Sea Otter and Shellfish Fisheries Forum
Third Annual Big Island Aquaculture Conference
Oceans '82
National Sea Grant Internship Program
Sea Grant Today

In 1981-82 the California Sea Grant communications staff also worked closely with numerous Sea Grant programs, including the USC Sea Grant program and the Sea Grant programs in Alaska, Hawaii, Massachusetts, New York, Oregon, South Carolina, Texas, and Washington, to produce regional and national Sea Grant publications and to support events of mutual interest.

The communications staff also focused on improving program visibility and information dissemination by issuing short press release announcements highlighting California Sea Grant program accomplishments and research results. During a 5-month period, the communications office prepared six press releases and distributed more than 7000 copies to elected officials; federal, state, and local agencies; university public affairs officers; educational leaders; industry officials; non-profit organization heads; the news media; members of the Sea Grant network; and the general public.

In many cases these short press releases generated further dissemination of Sea Grant program information to national and international audiences. For example, a press release on the squid cleaning machine developed by Sea Grant researchers at UC Davis resulted in a feature story released to 390 radio stations in the U.S. through the Copley Radio Network. A press release on mollusc cultivation techniques developed by a Sea Grant researcher at UC Santa Barbara led to a cover story and four-page article in *Aquaculture Magazine*, a subscription-only special interest magazine currently circulated in 50 states and in 82 foreign countries.

An important goal of the communications project in 1981-82 was to increase dissemination of California Sea Grant program information to regional, national, and international audiences.

This year we produced two valuable technical publications that have wide audience appeal. *A Manual for Researching Historical Coastal Erosion*, written by a science writer intern from UC Santa Cruz, was a departure from the traditional technical publications produced by our program. Instead of reporting the research data resulting from Sea Grant's seven-year commitment to historical erosion research in California, Sea Grant produced a practical guide outlining the basic steps involved in researching historical erosion in a given area. Because the manual can be used by professionals and laymen, we actively pursued wide distribution of this publication. To date, more than 850 copies of the manual have been distributed to local, state, and federal agencies; city and county planning directors; coastal commissioners; conservation organizations; university geology department chairmen; state and federal elected officials; libraries; and interested individuals throughout the U.S. and abroad.

Requests for the publication have come from all parts of the U.S. and the world, including Arizona, California, Maryland, Massachusetts, New Jersey, Oregon, Virginia, and Australia, Japan, Mexico, and Nigeria. Kudos for the publication have come from many audience sectors, including the California Coastal Commission, the U.S. Department of the Army (Corps of Engineers), the New York State Department of Environmental Conservation, the University of Rhode Island, the Advisory Council on Historic Preservation, and the National Oceanic and Atmospheric Administration.

In 1981-82 California Sea Grant also produced *Mariculture of Red Seaweeds*, by Dr. Hansen, et al. Red seaweeds, relatively unknown by the layperson, are much needed by food processors and biomedical researchers. U.S. dependence on imported seaweed stocks has created a demand for red seaweed that exceeds the supply provided using traditional harvesting techniques. This book relates seaweed mariculture — in both its historical and political perspectives — to the development and recent success of red seaweed cultivation research in the U.S. and abroad.

Because the development of our seaweed resources is of widespread concern, California Sea Grant communications staff worked with researchers at the University of Guam and the editors of *Aquaculture Magazine* to promote the book's national and international dissemination. This cooperation resulted in the publication's wide distribution and acclaim in public, private, and government sectors. Letters we've received to date praising the book's value have come from California, New York, Oregon, Virginia, Canada, Guam, India, Puerto Rico, Sweden, Switzerland, and Taiwan.

Copies of the book were provided by request to participants of an international course in marine algae sponsored by the European Council and UNESCO, which brought together researchers from Belgium, Chile, England, France, Germany, Italy, Morocco, Spain, Sweden, Switzerland, Turkey, and the West Indies. Requests within the U.S. have come from Alaska, California, Washington, and Washington, D.C. In response to its high demand, the publication was reprinted six months after its first press run. To date more than 1500 copies have been distributed.

In 1981-82 we also introduced our fourth new publication series, the Working Paper Series. The series was established to make preliminary data, research techniques, and reports under publication consideration available to government agencies, industry, fishermen, and related user groups. In a working paper, neither the research results presented nor the publication itself has undergone critical peer review according to the guidelines of the California Sea Grant College Program publications policy.

The first publication produced in the Working Paper Series was *The California Interindustry Fisheries (CIF) Model, Volumes I and II*, by Drs. Dennis King and Kenneth Shellhammer of the Center for Marine Studies at San Diego State University. The CIF Model was prepared to evaluate the direct, indirect, and induced economic impact of fisheries on California's economy. To date the model has been used to evaluate the economic impact of four situations affecting the state: a proposed ban on gill net fishing, closure of a portion of the salmon season, a plan to translocate sea otters, and a proposal for a fish offloading facility for the port of Santa Cruz.

Copies of the CIF Model have been distributed by request to nearly 300 legislators, consultants, government agency officials, and private groups interested in determining the economic value of the state's fisheries.

We designed the 1980-81 summary in a news magazine format to help "get the word out" about California Sea Grant research results and, at the same time, to reduce production costs of standard publications. With the summary's headlines, datelines, and bold type, readers were quickly able to identify California Sea Grant research in their geographic area. By using less expensive paper and modifying the summary's design, we reduced our unit production cost nearly 40 percent for a total savings of nearly $3000.

The summary's news magazine format proved especially valuable to elected officials, university public affairs officers, government agency heads, and media contacts whose interest in Sea Grant research and accomplishments is limited to specific regions and subject areas. In particular, the summary proved to be an effective tool in introducing our program to the media and interesting them in Sea Grant research results. New media contacts made in 1982 in response to stories reported in the summary included representatives from KPBS (the local public broadcasting station), United Press International (UPI) in San Francisco, Walt Disney Productions, and *L'Espresso Magazine*, (the Italian equivalent of *Life Magazine*).

In 1981-82 we also redesigned the program directory to improve its effectiveness and to reduce unnecessary production costs. The directory was typeset and printed in a format suitable for mailing in a business size envelope, a reduction in total size of more than 60 percent. By producing a smaller directory, we reduced unit production cost more than 40 percent and mailing costs by 73 percent, for a combined savings of $7600.

In 1981-82 our computerized distribution system continued to grow by about 5-10 names per week. Each individual in the system is coded according to the areas of interest selected on a mail list card. With this coding, the system can provide split-second compilation of lists of individuals by subject area. Using this capability, we sent publication announcements to individuals according to their expressed areas of interest. The response was dramatically successful: response rates that are traditionally 1 to 5 percent increased to 28 to 48 percent, with an average response of 36 percent. Nearly 13,000 fliers announcing California Sea Grant publications were mailed in 1981-82.

Our increased dissemination efforts in 1981-82 resulted in a dramatic 71 percent average increase in requests for publications in the CSGCP publications series, which do not include publications produced and distributed by the Marine Advisory Program (MAP) at UC Davis. Overall, we received 12,000 unsolicited requests for publications in FY 82, representing a 7 percent increase over FY 81.

Broken down into audience sectors, CSGCP publication requests (not including MAP) are listed in table 1. With the improved dissemination efforts put into place in FY 82, it is anticipated that the communications project will continue to experience similar growth.

Table 1

Group	Percentage of Requests	# of Requests Percentage Increase over FY 81
Government Agencies	26	16
Industries	15	47
Educational Institutions	37	79
General Public	22	143

Publications

ANDERSON, K. E. 1981. Directory of academic marine science programs in California: community colleges, four-year colleges, and universities. Report No. R-CSGCP-003. California Sea Grant College Program, La Jolla, CA.

ANDERSON, K. E. 1982. California Sea Grant College Program Annual Summary 1980-81. Report No. R-CSGCP-008. California Sea Grant College Program, La Jolla, CA.

CHAVE, E. H., MCCORD, C., ADERKEROI, D., BUKERROU, H., KATOSANG, S., AND SADANG, P. 1981. Palau's marine ecosystems: filmstrip narrative. Report No. E-CSGCP-001. California Sea Grant College Program, La Jolla, CA.

EKLUND, L. F. 1981. Using California's marine resources: A summary report on the California Sea Grant College Program 1979-80. Report No. R-CSGCP-005. California Sea Grant College Program, La Jolla, CA.

FAWCETT, J. A., MANUS, A. T., AND SORENSEN, J., EDS. 1981. Proceedings of a Forum on Recreational Access to the Coastal Zone. Report No. T-CSGCP-005. California Sea Grant College Program, La Jolla, CA. (In cooperation with the University of Southern California, IMCS Report).

FULTON, K. 1981. A manual for researching historical coastal erosion. Report No. T-CSGCP-003. California Sea Grant College Program, La Jolla, CA.

GERWICK, B. C., HOLLAND, T. C., AND KOMENDANT, G. J. 1981. Tremie Concrete for Bridge Piers and Other Massive Underwater Placements. Report No. T-CSGCP-004. California Sea Grant College Program, La Jolla, CA. (In cooperation with the Federal Highway Administration, Report No. FHWA-RD-81).

HANSEN, J. E., PACKARD, J. E., AND DOYLE, W. T. 1981. Mariculture of red seaweeds. Report No. T-CSGCP-002. California Sea Grant College Program, La Jolla, CA.

ILES, A. AND ANDERSON, K. E. 1982. California Sea Grant 1982-83 program directory: making waves. Report No. R-CSGCP-009. California Sea Grant College Program, La Jolla, CA.

KING, D. M. AND SHELLHAMMER, K. L. 1981. The California interindustry fisheries (CIF) model: an economic impact calculator for California fisheries (volume I). Report No. P-T-5. California Sea Grant College Program, La Jolla, CA. (In cooperation with the Center for Marine Studies, SDSU, Technical Report No. 82-1).

KING, D. M. AND SHELLHAMMER, K. L. 1981. The California interindustry fisheries (CIF) model: an input-output analysis of California fisheries and seafood industries (volume II). Report No. P-T-6. California Sea Grant College Program. La Jolla, CA. (In cooperation with the Center for Marine Studies, SDSU, Technical Report No. 82-1).

LEIGHTON, D. L. AND PHLEGER, C. F. 1981. The suitability of the purple-hinge rock scallop to marine aquaculture. Report No. T-CSGCP-001. California Sea Grant College Program, La Jolla, CA. (In cooperation with the Center for Marine Studies, San Diego State University contribution No. 50).

PUBLICATIONS POLICY AND REVIEW COMMITTEE. 1980. Publications policy: California Sea Grant College Program. Report No. R-CSGCP-002. California Sea Grant College Program, La Jolla, CA.

SEA GRANT. 1980. California Sea Grant College Program directory 1980-81. Report No. R-CSGCP-001. California Sea Grant College Program, La Jolla, CA.

SEA GRANT. 1981. California Sea Grant College Program: ocean research, ocean education, marine advisory service. Report No. R-CSGCP-006. California Sea Grant College Program, La Jolla, CA. (Brochure).

SEA GRANT. 1981. California Sea Grant College Program directory 1981-82. Report No. R-CSGCP-007. California Sea Grant College Program, La Jolla CA.

THORNLEY, K. 1981. Summary report of marine education in California public schools, kindergarten through twelfth grade. Report No. E-CSGCP-002. California Sea Grant College Program, La Jolla, CA.

OCEAN EDUCATION FOR THE PUBLIC

University of California, San Diego
University of California, Santa Barbara
University of California, Santa Cruz
Moss Landing Marine Laboratories
Humboldt State University
A/PE-1
1980-82

Donald W. Wilkie, David Coon,
William T. Doyle, Jennifer Anderson,
Michael S. Foster, Bruce A. Stewart
John D. DeMartini and John G. Hewston

Scripps Institution of Oceanography, UC San Diego

The objective of this project is to increase public understanding of both marine science and the California coastal marine environment through education programs for students, teacher-training programs, museum exhibits, and information services for the general public. Knowledge of humanity's impact on the ocean and its inhabitants is vital for current and future voters who will help shape national policies on ocean resource management.

The Aquarium-Museum has received Sea Grant support for public education since 1970. The original grant provided administrative and operating expenses for a field-trip program given at the Aquarium-Museum by trained docents. Modest increases in subsequent grants initiated a burgeoning of educational activities. These activities are described below.

Since 1978, Sea Grant support has become more necessary than ever as county and city funds for education have diminished due to the effects of Proposition 13 and the national recession. As the Sea Grant marine advisors have less and less time for public education because of budget and staffing constraints, communication of Sea Grant aims and goals may be more effectively promulgated by the universities taking part in ocean education for the public.

School field trips. All field-trip programs in California are in a state of flux due to budgetary cuts produced as a result of Proposition 13 (enacted in 1978), the court-ordered busing for desegregation creating a shortage of buses for field trips, and the national recession. The number of field-trip participants increased from 33,209 in 1970 to 62,504 in 1977, but has declined since 1978. Last year, there were only 37,615 participants.

Docent training program. Docents are volunteer guides trained to work with the student groups who make field trips to the Aquarium-Museum. The docent-training program has been expanded into a 12-week lecture and laboratory course, with slides, films, living and preserved specimens, and pertinent field trips. Ongoing monthly lectures by staff members provide continuing training and information. A $10.00 fee helps defray expenses for workbooks and biological specimens.

Outreach program. In an effort to reach classes that are unable to make field trips to the Aquarium-Museum, our docents travel to the schools. In 1980-81, they went to 36 schools to teach 2,558 students. In 1981-82, we more than doubled this program to reach 5,841 students serviced by eight docents providing their own transportation.

GATE. The Gifted and Talented Education Program is a state-mandated program for gifted students. For the fifth year now, they have requested we teach a 1-week course on marine biology and oceanography at 14 schools. The state pays our teacher's salary, and we provide the teaching materials.

Enrichment courses. We have taught a variety of classes, ranging in length from 1 hour to 1 week, in conjunction with various federally funded programs. For 5 years, at the request of the Emergency School Assistance Aid director, three of our docents traveled to six minority schools to give special units in marine science. We also teach in the science and math magnet schools in San Diego city schools. Such enrichment courses depend on the amount of federal funding available and vary year to year.

In-service training for teachers. The Aquarium-Museum offered its twelfth annual environmental symposium for teachers, with lectures on current research primarily by Scripps scientists on marine mammals. In response to continual teacher requests for more training programs, we developed two intensive (14-hour) weekend courses (one given in the fall and one in the winter) entitled "Living in a Watery World." One was entitled "Tidepool Life" and the other "Fishes, Shorebirds, and Marine Mammals." Two 30-page workbooks were developed for classroom use.

Summer minicourses. During the summer, we are able to offer more intensive courses from 1 to 6 weeks in length. Eleven courses have been developed covering tidepools, estuaries, marine mammals, ecology, and oceanography. Over 600 students from first through twelfth grades attended last year, learning about the foodstocks, the mineral resources, hydrothermal vents, and the effects of humanity on the ocean and its inhabitants. One of these courses is an intensive 6-week field experience course for high school students who are considering a career in ocean sciences or aquariology. Fees charged for all these courses pay for salaries and materials, and also provide income for such materials as films, filmstrips, and lab materials.

Junior Oceanographer Corps. Between 100 and 150 families belong to this organization for fourth grade through high school students. There are monthly lectures primarily by Scripps scientists, and weekend field trips studying various marine environments.

San Diego-La Jolla Underwater Park guides. The beach and tidepool areas near Scripps are part of a marine preserve dedicated to research. For many years, Aquarium-Museum docents have participated in a tidepool patrol to provide information to the public and by their visibility to encourage conservation and protection of the intertidal environment.

National Marine Education Association conference. This August, the Aquarium-Museum hosted a national conference of 241 teachers from California and across the nation on our University of California, San Diego campus. Among the 71 speakers were 15 senior Scripps scientists with reports on the latest oceanographic research, exchanges of teaching materials developed by various teachers on ocean-related topics, curriculum specialists, and suggestions of classroom activities at different grade levels. The Aquarium has participated in the NMEA for several years, and was instrumental in organizing the southern California branch last year (Southwest Marine Education Association.) This group of teachers, aquarium and natural history museum scientists, Sea Grant college specialists, and department of education personnel is a particularly concerned group dedicated to enriching students' background knowledge of ocean sociological effects, history and literature, and the current and future impact of mankind on the inhabitants and mineral resources of the world's oceans. The enthusiastic exchange of ideas, education materials, and classroom activities at the meeting was particularly pleasing and efficacious.

Preparing and publishing educational materials. Providing educational materials for teachers to use in their classrooms has been a continuing project at the Aquarium-Museum. Two bibliographies have been produced, one on oceanography and one on sharks. An aquarium manual, "Maintaining Marine Animals," and a booklet, "Tides and Grunion," were written. Two teaching manuals for use in elementary schools are "Living in a Watery World," Part I (Tidepool Life) and II (Fishes, Shorebirds, and Marine Mammals). Seven workbooks for our summer school minicourses have been developed: grades 1,2,3, Oscar Oceanographer and Sammy the Sea Otter; grades 4,5,6, Tidepool Life, Estuaries and Wetlands, and Marine Mammals; grades 7,8,9, Marine Ecology and Physical Oceanography. In preparation is a fifth and sixth grade manual on oceanography designed to be useful for teachers throughout the state. Education packets for all teachers who make field trips to the Aquarium-Museum are updated annually.

Advisory services. Staff members have replied to both written and verbal requests on a wide variety of marine subjects, from scientific investigation to maintaining marine aquaria. Teachers and school districts have been assisted in developing marine courses, worksheets and teaching materials. In addition, slides, films, and filmstrips have been loaned to teachers and scientists for a modest fee.

This project is designed to increase and enrich public awareness of the world's oceans and the California coastal zone. The key target group is today's school children who will be tomorrow's voters, decision makers, and implementors. Sea Grant support is the foundation of the education program at Scripps Aquarium-Museum.

Marine Science Institute, UC Santa Barbara

The goals of this program are to increase community awareness of marine resources and the research activity of the University of California in the field of marine science. The program is designed to fill an existing need by responding to a demonstrated interest in marine science in the regional communities.

With Sea Grant support, the Marine Science Institute at the University of California, Santa Barbara (UCSB) annually hosts visitors from the local region (some travel more than 100 miles to reach the lab) on special tours at the campus Marine Laboratory. These tours are scheduled for 4-5 days at the end of each academic quarter, when marine laboratory classroom space is not in use. Groups are taken through the lab under the guidance of UCSB undergraduate and graduate students, who have been given an orientation session in which the topics and areas of emphasis are defined. Extensive diving collections of local organisms are used to create displays which accurately represent the diversity of the local marine and coastal environment.

For each group, the typical program includes a tour of the marine laboratory lower level, where UCSB student guides discuss organisms in permanent and temporary aquaria displays, flora and fauna in special shallow "handling tanks," diving gear and boatyard equipment, and larger animals (such as small sharks, moray eels, large lobsters, etc.) and plants held in large circular seawater tanks. Microscope displays, shallow aquarium tables that permit handling of the organisms, and poster presentations are set up in laboratory areas normally occupied by university classes. Depending on group interests and time, beach walks and visits to research laboratories are provided. The undergraduate and graduate students employed under this program assist in collecting the organisms, arranging the displays, and conducting the tours. The modest economic benefits for the guides are important, but the students find working on the program very rewarding in other ways as well. They have an opportunity to use and review their knowledge, to share with others their interest in this field of study, and to organize and practice communicative skills. Many students "repeat" as guides and provide experienced help for the program.

During the past year, due to budget reductions, the evening tour program was dropped. Because late afternoon hours were the last to be scheduled by visiting groups, an additional day of tours was added, and the number of tours per day reduced by one. This schedule resulted in our being able to accomodate almost as many visitors as before and will be retained during the present year.

Since the program's initiation, it has been our procedure to ask participants for their views and suggestions for improvements. Evaluation forms are sent out following each quarter's activity for return by mail. The high rate of return of these forms (50-80% over the last 2 years) is in itself an indication of the value of the program to the participants.

Specific comments also indicate that we are providing a useful public educational experience: "fills a void in Santa Barbara," "I fit my program around your tour," "an 'adult education' item and more." Many of the comments show that the benefits are extended by outside preparation and coursework. Participants are often part of a special class or science group, involved in marine life studies in their regular lessons, or doing marine life projects. Instructors may make special lessons to correlate with the visit.

Increased public interest in the

research activities of the university is beneficial to UC and to Sea Grant. Our student guides, frequently complimented on their work, help increase public awareness and appreciation for the undergraduate educational program at UCSB.

In summary, this small public education program provides an opportunity for visitors to learn firsthand about the marine life of the Santa Barbara region and to become acquainted with the marine research programs of Sea Grant and the University of California.

Center for Coastal Marine Studies, UC Santa Cruz

Program development for the Ocean Education for the Public program is a continual process. Ongoing review and evaluation focuses primarily on the interpretive and academic training for the interns, the quality and variety of offerings to the public, program administration, and the cooperative links with other participating agencies. This year the following changes, additions, or observations were made.

The cooperative program with Long Marine Lab has added new depth and dimension to the Ocean Education for the Public program. It allows the public the opportunity to see and to understand a marine research facility, the students the chance to become aware of current research projects and to work in an indoor interpretive setting, and the faculty a way to disseminate information (through the interns) resulting from their most recent work. Many school and other groups visited both the intertidal area at Natural Bridges and Long Marine Lab and felt that the two visits complemented and enriched each other. It was also an advantage to be able to offer an alternative trip to Long Marine Lab when the tides were high or the weather was bad.

The interaction between the existing docent program at Long Marine Lab and the student interns also proved to be a mutually beneficial exchange of information and techniques. The docents had a series of training and educational sessions that the interns attended, and the interns brought strong academic backgrounds and new interpretive ideas to the docents.

The development of the training manual for interns was a critical step in assuring program continuity from quarter to quarter and year to year. It established clear procedures for general functions of the internship including scheduling and sample tours and provided a framework for interpretive and scientific information. Time spent in seminars introducing the internship can now be saved by having the students read the manual and can be used in more constructive on-site training activities.

A large variety of slide shows and tour sites now exist within the program. The slide shows include the following:

a. Intertidal, grades K-3
b. Intertidal, grades 3-6
c. Intertidal, junior and senior high
d. Elkhorn Slough (developed this year in conjunction with Moss Landing Marine Lab)
e. Natural History of Año Nuevo (added to the program this year)
f. Natural History of Elephant Seals (added to the program this year)

Normally student interns take these slide shows out to schools and present them. If no intern is available, slide shows may be checked out with an accompanying script. The following sites are now available in the program:

a. Natural Bridges State Beach (intertidal and sandy beach)
b. Elkhorn Slough (Nature Conservancy land)
c. Long Marine Lab (interpretive center and surrounding land including Younger Lagoon)
d. Santa Cruz City Museum

A program coordinator was hired instead of using student interns to handle administrative and training aspects of the program. It was felt that this was an extremely successful model and we will continue to use it this year. In addition to the development of curricular materials such as the Elkhorn Slough slide show and the training manual for interns, the positive accomplishments include altering the coordinator's position to provide program continuity throughout the year, increased liaison and personal contact with the outside agencies that participate in the program, organization of training seminars, more frequent field evaluation of students, coordination of more relevant term projects for students and agencies involved (see attached list in narrative), and reorganization and refinement of procedural aspects of the program, especially scheduling. There has been a marked increase in the number of students and public who participate in the program and also in the quality of the program in general. This can be directly attributed to the coordinator's position.

Part of the interpretive training for the Elkhorn Slough interns was a field visit to the newly established estuarine sanctuary at the slough managed by the California Department of Fish and Game. Possible connections between our two programs were discussed and some very interesting possibilities were presented. It seemed premature to follow up on these this year because of access problems to the site; however, a cooperative program will continue to be explored.

Student interns again participated in the University's open house by presenting current slide shows and by being available to explain the Ocean Education for the Public program. This year part of the open house was at Long Marine Lab, and because our students were familiar with this site, they also led tours of the lab and made displays for the open house.

The class, Environmental Interpretation, Environmental Studies 179, was taught for the second time and it continues to be the major source of interpretive preparation for all the interns in the program. It also serves as an arena to foster program development ideas, to share and implement successful techniques and experiences, and to discuss problems which occur in the program. It will be continued this year.

Adding the Año Nuevo slide shows to our outreach program not only enriched our offerings, but also allowed us to reach a more diverse audience. Since the program focuses primarily on the presentation of slide shows, it enabled us to contact professional community groups and senior citizen groups who were not necessarily concerned with a follow-up field trip. There was also a very fruitful interaction between this aspect of the Ocean Education for the Public program and the Environmental Studies interns who were giving tours at Año Nuevo.

The record keeping for program participants which was implemented last year was continued this year and a complete list of groups served is now being compiled. The number of interpretive contacts this year has increased dramatically as well as the student participation (again, this is attributed to our revised and more efficient form of program administration).

Moss Landing Marine Laboratories

The overall goal of Moss Landing Marine Laboratories' (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 Day. Since 1979, approximately 4,000 students have toured MLML during Visitor Days. In response to an overwhelming demand, the original 3-day format has been expanded to 4 days. About 1200 students from private and public schools and service groups (such as Cub Scouts, Girl Scouts, and 4-H) attended the 1981 Visitor Days. 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 1981 Visitor Days invitation was so great that by the first morning of registration, all the slots were full. These students 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 10 to 15 each and led through the various stations by MLML graduate students.

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 and questionnaires distributed to MLML personnel indicated 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 equipment for seawater analysis), displays concerning ongoing research, nature walks, and a variety of slide shows and movies. A puppet show presented marine ecology concepts in a way children could understand and received enthusiastic response from viewers of all ages. The 1978 Spring Open House was so well attended (over 5,000 in one day) and appreciated by the public that following open houses were extended over 2 days. This resulted in decreased crowds and increased interpretive quality. The duration of the 2-day open house is Saturday from 10 a.m. to 12 noon 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 noon to 4 p.m. for the general public, and Sunday 10 a.m. to 4 p.m. for the general public.

The theme of the 1981 Open House was "Research at Moss Landing Marine Laboratories," a repeat of the very popular 1980 theme. Students and faculty made a special effort to present most facets of current research activities at MLML to the public, with an emphasis on in-person interpretation of displays.

The general success rating from feedback questionnaires was 9 on a scale of 10 (1 designated a "waste of time," 10 a "great experience"), with 10 receiving the most votes. One hundred percent felt the Open House was educational and 87% felt the technical level of the exhibits and presentations was just right (9% felt the level was not technical enough; 3% felt the level was too technical). At the top of a long list of items in the "most liked" column were the live exhibits (aquaria, 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" (15%) and other responses were varied (none represented more than 0.5% of all respondents). Most people said they attended the Open House for information (76%) or entertainment (50%) and 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.

Mentally Gifted Minor (MGM) Marine Biology Workshop. In response to a request by the North Monterey County Unified School District, MLML students presented a 1-month MGM marine biology workshop in October 1980 for students in grades 2-8. A local community center provided space, MLML provided materials (microscopes, aquariums, live animals, etc.) and boat time, and the Sea Grant Public Education Coordinator organized and supervised the workshop. The school district MGM program provided $900 which paid 10 graduate students a stipend 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. Each session was prepared and taught by a graduate student in that area of concentration.

Continuation High School Elkhorn Slough Minicourse. This summer, a local continuation high school requested a repeat of last summer's minicourse on the ecology of Elkhorn Slough for their students. Approximately 15 students were given previsit materials and an assignment to study available careers in wetlands biology, and each student researched a bird which could be expected to be encountered in Elkhorn Slough, noting feeding behavior, migratory patterns, habitat preference, etc. On site, they were given a tour of MLML facilities followed by a boat trip up the slough to observe man's influences on the slough (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.

A 2-week minicourse on Elkhorn Slough was provided for another continuation high school in 1979. This course included five lecture/lab sessions and five field trips covering such subjects as physical oceanography, plankton, plants, invertebrates, fish, birds, and mammals. Students learned first-hand about the controversy surrounding the impending designation of Elkhorn Slough as a Federal Estuarine Sanctuary by acting out a community meeting in such roles as fishermen, developers, biologists, and conservationists.

Intern Program. An intern program was initiated in which interested high school students take part in field research at MLML (for academic credit) under the supervision of an MLML scientist. Twelve students so far have participated in studies involving benthic and salt marsh ecology and trace metals and plankton.

Summer Marine Biology workshops. Over 200 children attended 2-week summer marine biology workshops in 1980, 1981, and 1982 at MLML. The courses, taught by MLML graduate students, 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. Lack of time, space, and funding make it impossible to fill this need completely. Such tours would also disrupt teaching and research. The Visitor Days program, the general Open House, and our outreach program alleviate some of the need, but we still get many requests for tours from schools and other community groups as well as from drop-in visitors. In 1981 and 1982 we averaged about three tours per month.

Outreach Program. We respond to as many requests for speakers as possible, mainly to local schools and community groups. We have gone as far as Oakland and San Jose for large assemblies. Sometimes presentations are given to one classroom, but more often to some type of larger assembly (e.g., career day or science fair). Presentations range from slide talks to bringing in diving equipment or a variety of live animals in a portable touch tank for the children to explore. In response to an ever-increasing demand, we expanded our outreach programs in 1981 and 1982. About 6,000 students of all grade levels (preschool through college) received slide talks on marine research activities and higher education and career opportunities, and/or live animal demonstrations. We averaged three outreach presentations per month in 1981.

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

Humboldt State University

The objective of this project is to interpret marine environments and their attendant biotas, especially those of the Trinidad Bay area and of northern California, for the public. The Telonicher Marine Laboratory is the center of such activity, with Greg Pic'l, graduate student, Department of Natural Resources and Planning, aiding the principal investigator. A portion of Pic'l's work will serve as substance for his master's degree project.

Our major thrust for meeting objectives has centered on the development of raw interpretive materials near and within the laboratory. For example, photos of living marine organisms have been taken in the intertidal zone and in shallow, subtidal habitats using scuba. Working in concert with Jay Brown, a graphic artist from Instructional Media and Developmental Services, Humboldt State University, we constructed panels including Cibachrome prints produced using 35-mm photos, graphics, and drawings. We are utilizing tanks for simulations of intertidal and subtidal habitats. We have visited various places like Steinhart Aquarium, San Francisco, to obtain ideas for constructing an intertidal tank. However, a lean budget has not allowed us to begin construction. Also, some competing needs of fisheries classes served as a deterrent.

To measure the effectiveness of our displays, we constructed test questions for the public. Dr. James Cunningham, Director, Institutional Research and Testing Center, assisted us in designing the test. A TRS-80 computer has been programmed so that individuals may take individual tests that monitor responses to multiple-choice questions, lets the testee know whether he has made the correct response and, if not, allows him to respond again. All responses are put into memory and can be subsequently retrieved. Dr. Dennis Anderson, Professor of Botany, helped us to develop the fairly lengthy computer program.

During the academic year, school groups, elementary through junior college, and others visit the laboratory. We attempt to have either Greg Pic'l or the principal investigator available to talk to groups. A special program can include explaining displays, conducting a complete tour of our facility, and giving a slide presentation on an aspect of marine biology. During our Open House held in May, 1981, we had well over 1000 visitors on a Friday and a Saturday. Various aids developed in this project and by students in fisheries, biology, and oceanography made for successful activity.

During the summer, many tourists visit the laboratory. The laboratory was not budgeted for being open on weekends. Dr. Alistair McCrone, President, Humboldt State University, was instrumental in procuring funds to have the laboratory open on weekends.

The education program has become known beyond the laboratory resulting in requests for programs to be delivered away from the laboratory. Local clubs and service groups, such as the local Audubon Society, Rotary Club, and Trinidad Garden Club, have requested presentations. After a recent presentation given by Pic'l to Trinity High School, Weaverville, California, he was asked to give an assembly on oceanography in the near future. Redwood National Park's interpretive staff is having about 50 of our 35-mm transparencies copied in triplicate for their interpretive programs. We have also been asked to conduct workshops.

The California Department of Parks and Recreation has been served by helping with the construction of an interpretive panel for Trinidad Beach State Park and by offering a workshop on marine interpretation for local state park rangers.

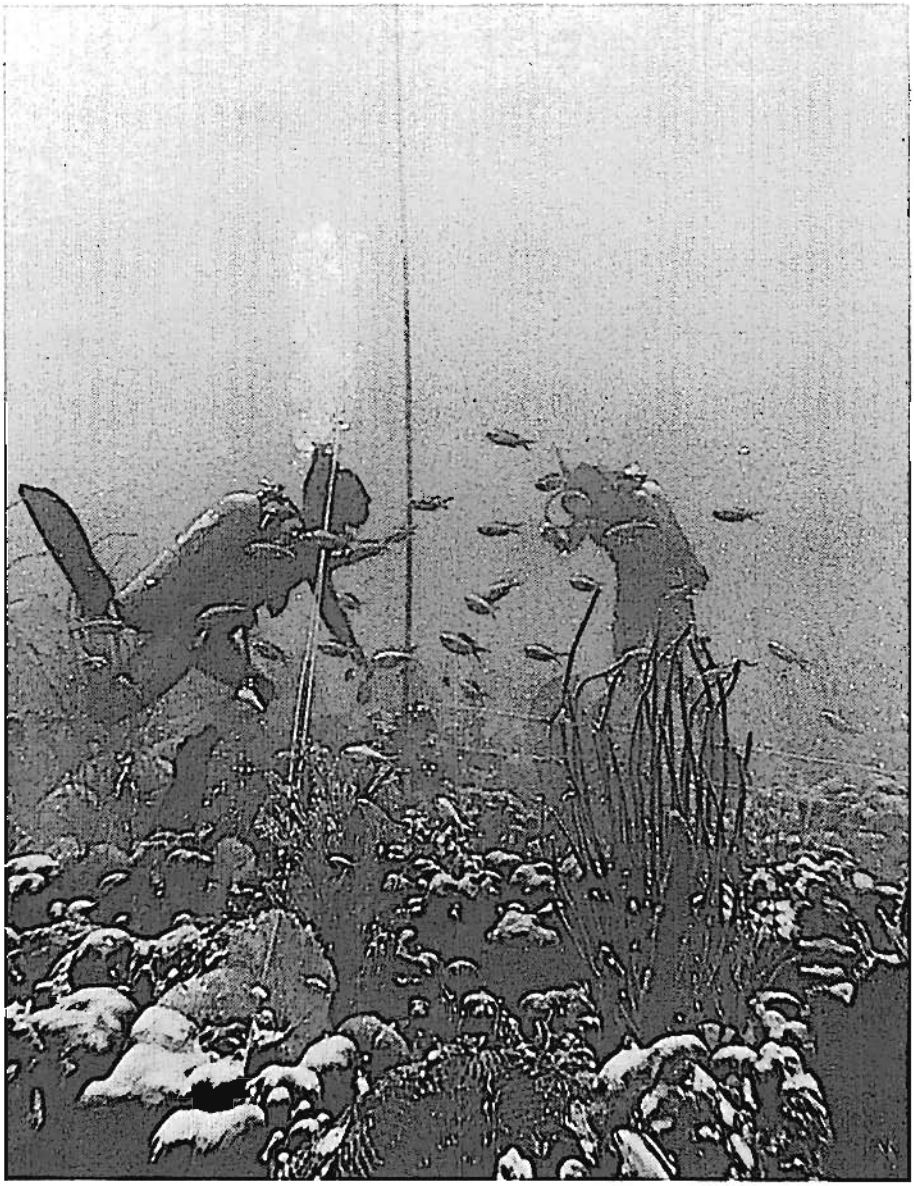
A master's thesis in natural resources interpretation entitled "Design, Development and Evaluation of Marine Interpretation for the Fred Telonicher Marine Laboratory" by Greg Pic'l is near completion. Mr. Pic'l has evaluated various means of carrying out interpretation including display panels, environmental simulations in tanks, and slide-sync-tape presentation. This information will be available upon completion of the thesis.

Cooperating Organizations

American Shellfish Enterprises
California Department of Parks and Recreation
California State Parks
Channel Islands National Park
Departments of Education of Monterey and Santa Cruz Counties
Humboldt State University Foundation
Long Marine Lab
Nature Conservancy
Santa Cruz City Museum
UCSC Marine Studies

Publications

Pic'L, G. 1982. Design, development and evaluation of marine interpretation for the Fred Telonicher Marine Laboratory. Master's thesis, Humboldt State University.



COASTAL RESOURCES

ANALYSIS OF COASTAL OCEAN MIXING MODELS

California Institute of Technology
R/CZ-48
1980-81

E. J. List and J. J. Morgan

It has been recognized for some time that most pollution of coastal waters is associated with fine particulate matter. Heavy metals and pesticides are carried to coastal waters by storm waters and treated waste waters discharged to the ocean. Whether these particles stay in suspension or are deposited as sediment depends upon two basic physical mechanisms, namely the ocean turbulence and the particle coagulation rate. Three physical phenomena cause particle collisions and, therefore, possible coagulation: Brownian motion, fluid shearing, and differential sedimentation. The first mechanism is well known and was described mathematically by Einstein and others. The second depends on the fluid turbulence, the third, the particle size distribution, which is, of course, a consequence of the coagulation.

Hunt (1980) succeeded in his Ph.D. thesis in describing coagulating particle size distributions under some rather restrictive hypotheses. These are primarily that only one mechanism is active over a size range, and that an equilibrium or steady state occurs with a uniform mass flux through the size distribution. Although the basic ideas were confirmed experimentally, the adequacy of these assumptions was not completely resolved because of an inability to describe the overall collision process in a time-dependent way. Extending these results to ocean waters is complicated by a lack of knowledge of the fluid turbulence within the density-stratified ocean.

The two recent goals of this project are, therefore, 1) to develop mathematical models of particle collision processes so that coagulation can be viewed as a time-dependent process, and 2) to measure fluid shearing motions in the turbulent coastal waters so that data is available for the models developed. Progress in each of these areas will be considered in turn.

Hunt succeeded in extending the work of air pollution physicists on aerosol particle size distributions to the coagulation of suspended particles in solutions of high ionic strength, such as seawater. The basic results obtained by Hunt were predictions of the number density of particles in a given size range that would result from each physical collision mechanism. The fundamental assumption was that an equilibrium would be established in which a steady flux of mass would travel through the size distribution from the smallest size particles (where mass is input) to the largest sizes where the mass would fall out from sedimentation. The theory applied dimensional analysis, as developed by Kolmogorov in fluid turbulence theory in the 1940s, to arrive at predictions for the size distribution in size ranges appropriate for each of the three collision mechanisms. Hunt's results are as follows:

Brownian motion

$$n(v) = A_b \left(\frac{E}{K_b}\right)^{\frac{1}{2}} v^{\frac{-3}{2}}$$

Fluid shear

$$n(v) = A_{sh} \left(\frac{E}{G}\right)^{\frac{1}{2}} v^{-2}$$

Differential sedimentation

$$n(v) = A_{ds} \left(\frac{E}{K_{ds}}\right)^{\frac{1}{2}} v^{\frac{-13}{6}}$$

where *n(v)* is the number density of particles in volume size range (v, $v+dv$), E is proportional to the flux of mass through the size distribution, K_b is the Brownian motion coefficient specified by the temperature and viscosity of the fluid, G is the fluid shear rate, K_{ds} is related to the fall velocity of the particles and A_b, A_{sh} and A_{ds} are numerical constants. Hunt was able to confirm these results experimentally for the first two mechanisms. The difficulty with Hunt's work is that it depends upon the two basic assumptions noted above.

In an effort to improve upon this approach, and at the same time evaluate the validity of the assumptions, a numerical computer simulation collision model has been developed that describes particle kinetics. The first model constructed was for the well-known Brownian motion. It was recognized that if the results already known for this process could not be reproduced, there would be little hope of progress in other areas. There was no difficulty in reproducing the equilibrium particle size distribution appropriate to Brownian statistics and for laminar fluid shearing motions. All of the known features of such collision processes were easily reproduced.

Including both Brownian motion and laminar shear motions simultaneously gives a reading on the degree of interference between mechanisms. Indications are that two distinct particle size ranges develop for the particle number density in a given size range (figure 1). The smaller particles collide by a Brownian mechanism to give the -3/2 slope, and the larger particles by the shear mechanism to give the -2 slope, on a number density-particle volume plot as predicted by the equilibrium theory. Both portions of the distribution seem to be the same as if the other process were absent, indicating independence of the processes.

The major recent progress has been in the development of a turbulence model (figure 2) in which the collision "box" is based on dimensions of the turbulence Kolmogorov microscale $\eta = (\nu^3/\epsilon)^{1/4}$, with ν the fluid viscosity and ϵ the rate of dissipation of turbulent kinetic energy per unit mass (related to the mean rate of strain $(\epsilon/\nu)^{1/2}$ in the fluid). The collision model box contains a three-dimensional strain field that varies on a time scale of $(\nu/\epsilon)^{1/2}$.

The model has been successful in reproducing the collision rate of monodisperse (uniform size range) particles predicted by Saffman and Turner (1956) (allowing for an error of $\pi^{1/2}$ in their paper). An interesting feature is that the equilibrium results are appropriate to a uniform laminar shear with the laminar shear rate replaced by 1.73 $(\epsilon/\nu)^{1/2}$, which strongly suggests that one-dimensional laminar shear models may be able to simulate the complex three-dimensional shearing of turbulent motions, so far as collisions are concerned.

In summary, we believe that we now have effective models capable of directly simulating two of the major particle collision processes for particle coagulation in the coastal ocean. Work is now proceeding on the differential sedimentation model. Technical scientific publications are being prepared describing the results obtained so far.

Ocean Turbulence Measurement

As noted above, one of the key elements in the description of turbulence-induced particle coagulation is the rate of dissipation of turbulent kinetic energy within the fluid (usually called ϵ). There are also indications that the variance of concentration fluctuations may have a secondary influence on the coagulation process. Very little data exists to describe the variation of ϵ within coastal waters, either with respect to depth or lateral displacement. The goal of this part of the project is to use a laser-Doppler velocimeter to determine ϵ and its distribution in the field. In figures 3 and 4 the layout of the laser transmission and receiving instrument packages is shown in photographs of the velocimeter. In figure 4 two laser beams are visible with the scattering beam appearing very bright and the reference beam weaker.

Progress with the development of this instrument has been disappointingly slow. Numerous laser failures occurred and a significant and difficult noise problem appeared in the photo diode output amplifier. However, the instrument has now been tested in the water and data collection will begin within a month or two.

An instrument similar to this has revolutionized velocity data measurement in the laboratory and there is every reason to believe that once the "bugs" are out, it should do likewise for coastal oceanographers.

The work to date has been primarily performed by two postdoctoral fellows and one graduate student. Dr. Gregory Gartrell is responsible for the laser-velocimeter development, and Dr. Henry Pearson and graduate student, Iraklis Valioulis, for the particle simulation studies.

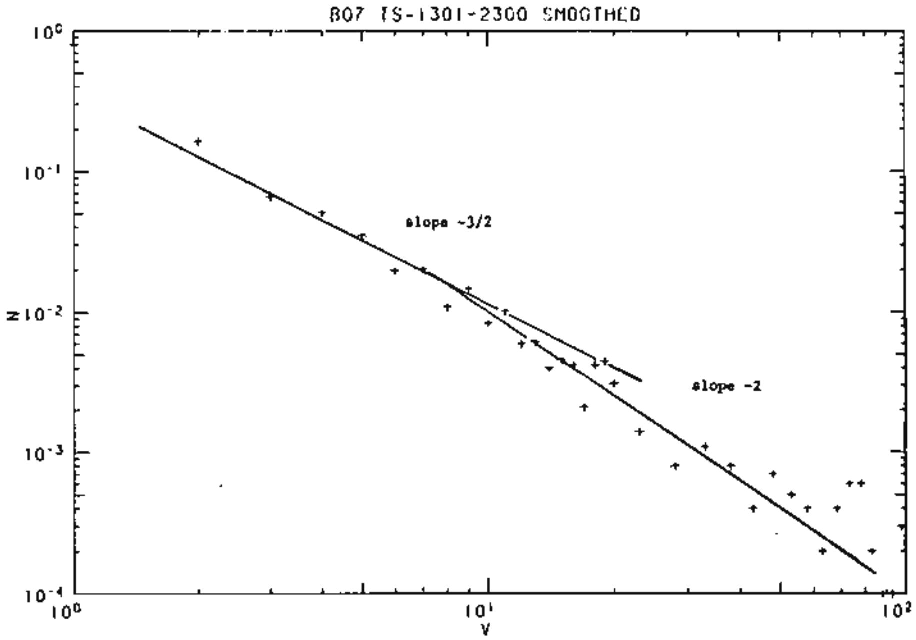


Figure 1. Particle number density versus particle volume for a collision process in which both Brownian motion and laminar shear are active. Note -3/2 law appropriate to B-M and -2 law for laminar shear process.

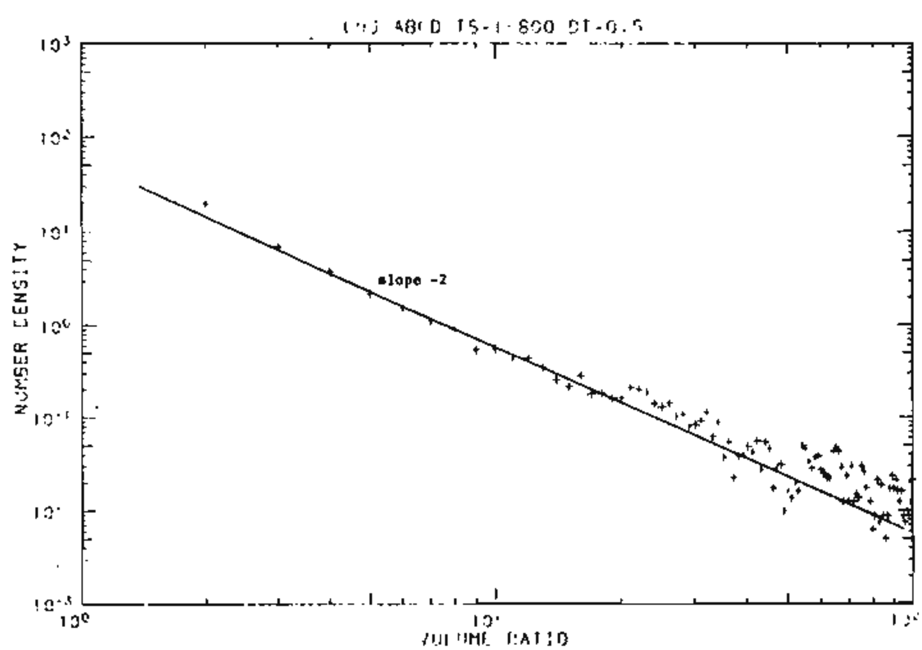


Figure 2. Particle number density versus particle volume for a turbulent shear-induced collision process. Note that simulation model produces the -2 law as for the one-dimensional laminar shear.

Cooperating Organizations
Mellon Foundation
National Oceanic and Atmospheric Administration
National Science Foundation

Publications

GARTRELL, G. AND PEARSON, H. J. On the scaling of the vertical diffusivity in stably stratified flows. Journal of Physical Oceanography. (Submitted).

GARTRELL, G. Vertical flux measurements in a density-stratified shear flow. In *Proceedings of the second international symposium on stratified flows.* The Norwegian Institute of Technology, Trondheim, Norway, June 1980.

HUNT, J. R. Particle dynamics in seawater, implications for predicting the fate of discharged particles. Environmental Science and Technology. (Submitted).

HUNT, J. R. Self-similar particle size distributions during coagulation; theory and experimental verification. Journal of Fluid Mechanics. (Submitted).

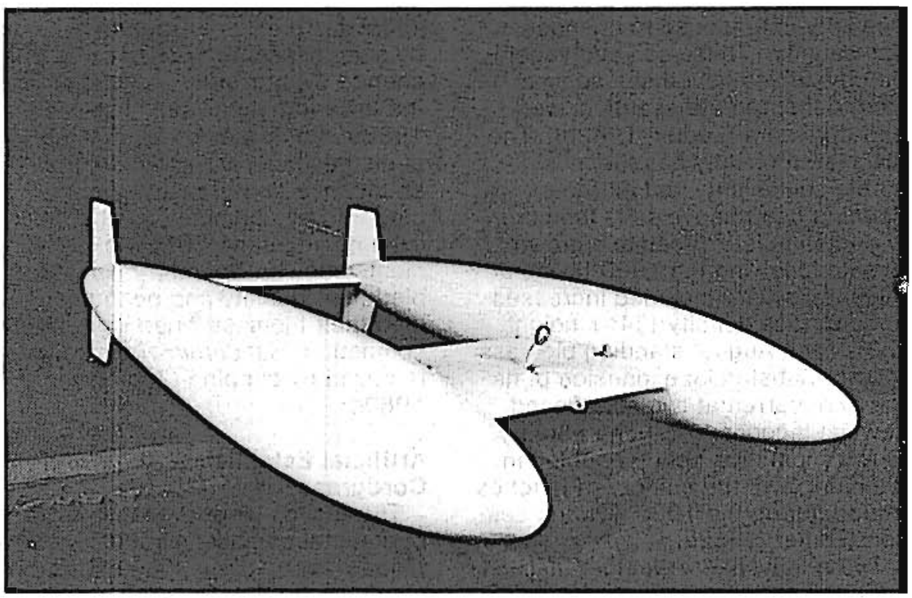


Figure 3. Photograph of laser-Doppler velocimeter showing laser beams in operation. Note high-intensity scattering beam and weaker reference beam. Receiving photo diodes in back hull.

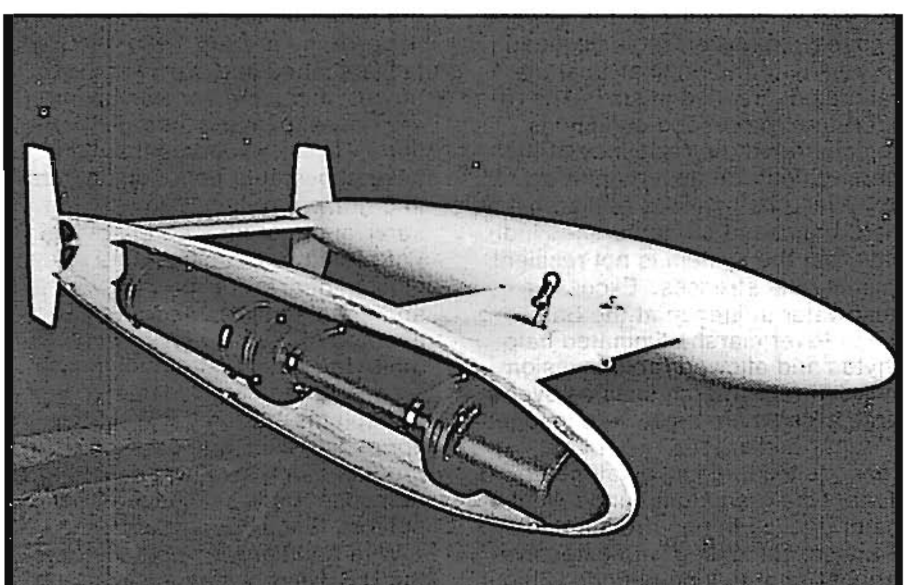


Figure 4. Laser instrument package revealed by hull removal.

COASTAL WETLANDS MANAGEMENT: RESTORATION AND ESTABLISHMENT

San Diego State University
R/CZ-51
1980-82

Joy Zedler

During 1980-82, the overall project goal "to provide ecological guidelines for the restoration and establishment of wetland communities" was achieved through preparation of several publications and through direct interaction with managers from state and local agencies. The research project neared completion just as several wetlands were designated for restoration by the California Coastal Commission and the California Coastal Conservancy. Hence, Sea Grant-sponsored research has played a major role in directing the course of coastal wetland restoration.

Three documents prepared specifically for the management community have provided information to a broad range of interested groups. The first, "The Ecology of Southern California Coastal Salt Marshes: A Community Profile" (Zedler, 1982d), summarizes information from the project and cites 180 references pertaining to the topic. The final chapter on management implications gives general advice on restoration, but experimental results and specific techniques are summarized in a companion document entitled "Salt Marsh Restoration: A Guidebook for Southern California" (Zedler, in prep.). The first draft has been circulated to users for their information and review. The state-of-the-art of marsh vegetation restoration was reviewed and presented to an audience of 240 users at the Wetlands Restoration Workshop in February 1982 (Zedler, Josselyn, and Onuf, in press).

We have also achieved the specific research objectives of 1) understanding the natural distributions of marsh vegetation, 2) establishing cordgrass (*Spartina foliosa*) and determining limiting factors for successful transplantation, 3) propagating cordgrass from seed, and 4) providing information to wetland managers. These findings are summarized below, with reference to appropriate publications.

Factors Controlling Natural Distributions

Examination of changes in cordgrass and other salt-marsh species under a variety of environmental conditions revealed rapid changes in distributions and productivity in response to changes in soil salinity. These soil and vegetation dynamics have been summarized to incorporate events in wet and dry years (Zedler, 1982b). The low marsh usually has the most stable soil salinity, but extreme flooding can remove salts temporarily and stimulate vegetative growth. Events following the 1980 floods at Tijuana Estuary included increases in cordgrass density (24%), height (23%), and August standing biomass (40%). Substantial expansion of its range occurred at two abandoned sewage lagoons in Tijuana Estuary. Existing patches nearly doubled in diameter, and the number of patches tripled during the 1980 growing season (Zedler, 1982d).

The relatively dry weather in 1981 provided an opportunity to follow vegetative responses as hypersaline conditions returned. In the natural salt marsh, height, density, and August biomass of cordgrass declined to 1979 values, while at the sewage lagoons, expansion rates declined and many of the original *Spartina* patches decreased in size. The rapid return to preflood conditions demonstrated the resiliency of the marsh to natural disturbance events. However, observations of man-made disturbances at other marshes indicate that the system is not resilient to abnormal stresses. Excessive freshwater influence at the San Diego River marsh eliminated halophytes and allowed rapid invasion by freshwater marsh species over a large area where soils were leached of salts (Zedler, 1981). At Los Peñasquitos Lagoon, alkali heath (*Frankenia grandifolia*) underwent a major decline in occurrence and biomass, coinciding with extensive drought (due to long periods without tidal circulation). In both of these cases, recovery is expected to be extremely slow for the following reasons. Many salt-marsh species (especially *Spartina foliosa*) have poor establishment ability. Most species reproduce best by vegetative means, and expansion occurs adjacent to existing clones. Seedlings are rarely seen, and expansion by seed seems to depend on chance events, such as flooding and the lowering of soil salinities (Zedler, 1982b and in press). Even if individuals become reestablished, their abundance and growth rates are hindered by competition with preexisting vegetation. Field experiments showed *Spartina foliosa* tripled their density and nearly doubled their biomass when its chief competitor, *Salicornia virginica*, was removed by clipping (Zedler, 1982d).

Artificial Establishment of Cordgrass

Three sites were available for experimental establishment of *Spartina foliosa*. Many of our 1979 transplants at the San Diego River marsh survived the 1980 flood, although they were temporarily lost in the invading cattail marsh which overgrew the area in summer 1980. Following the return of tidal influence and hypersaline soils in 1981, the cattails declined and surviving halophytes, including our transplants, are now expanding their distributions. These experimental plots have shown that both competitors and grazers reduced growth and survival of cordgrass transplants. With removal of competitors and exclusion of grazers, survival was 97% and each sprig planted produced an average of 3.2 new shoots. With other vegetation left intact, grazers tended not to find or damage the transplants, but only 74% of the sprigs survived, and each of these produced only two new shoots in response to the presence of competitors (Zedler, in press).

With additional assistance from the U.S. Navy, we have expanded the range of *Spartina foliosa* at the Tijuana Estuary abandoned sewage lagoons. Conditions following the 1980 floods were very favorable for expansion of transplants; densities increased from 36 to 269 on the average. Transplantation efforts have involved both seedlings and mature plants.

With assistance from the Port of San Diego, we rescued a variety of salt marsh species from Chula Vista's J Street Boat Basin, which was about to be dredged for marina development. Nearly 2700 plants were transplanted to the dike surrounding the South San Diego Bay dredge spoil island. (Slow settling of that island has prevented breaching of the dikes, so that intertidal habitats available for marsh establishment are restricted to the outer dikes.) Plants were utilized in experiments to assess the effect of elevation, slope exposure, and single- versus two-species mixtures. High mortality occurred in species planted outside their usual elevation range and on the slope exposed to heavy wave action. Best establishment occurred in a protected corner near a developing sand spit. The experiments suggest that *Spartina foliosa* and other marsh species have limited ability to stabilize dikes in southern California. Under normal hypersaline conditions, dike or shoreline stabilization would occur slowly, even with dense planting of *Spartina foliosa*. Unless planting coincides with years of heavy rainfall, or with freshwater irrigation, cordgrass will not achieve maximum growth rates.

Cordgrass Propagation

Transplantation of cordgrass from natural marshes is feasible, but marsh vegetation is too important for wildlife habitat to be disturbed by plant removal. Hence, artificial propagation is necessary for the establishment of low marsh vegetation.

We determined that the germination and early seedling stages are the most critical in propagation of *Spartina* from seed, and investigated the factors which affect seedling survival and growth (Zedler, in preparation). A major factor influencing germination ability is the condition of seeds collected. It is difficult to tell in the field whether seeds are likely to be viable. However, after a month's cold storage (4°C) in fresh water, seeds which are likely to germinate have swollen. Experiments with these "ripened" seeds showed that high temperatures with long photoperiods (12 hours light at 35°C and 12 hours dark at 20°C) shorten the average time for germination from about 2-3 months to 1 month. Germination stimulators were found ineffective (e.g., potassium nitrate) or detrimental (e.g., kinetin, gibberellic acid, thiourea, and slitting of seed coats) to germination of *Spartina*.

Seedlings grew best under greenhouse conditions. Outdoors, fresh water and shade were advantageous, suggesting that cordgrass is poorly adapted for establishment in the harsh environment of exposed mudflats. Insect grazing was substantial for seedlings grown in fresh water (51% were grazed). Seedlings growing in brackish and seawater showed less grazing (9% and 4% respectively). Seedling survival was higher (42%) in continuously saturated soils than in flats watered at intervals by a drip system (11%).

Attempts to increase tillering rates of cordgrass by pruning potted plants were detrimental. Hence, propagation from seed, although subject to the above difficulties, remains the best method for off-site production of *Spartina foliosa*. As an alternative management strategy, on-site propagation of cordgrass is advisable. A portion of the proposed marsh site should be set aside for initial planting and subsequent removel of sprigs for transplantation to larger areas. This calls for a longer-term implementation program than a single planting of seedlings, but costs should be lower because on-site propagation would be less labor-intensive.

Transferral of Information to Users

Involvement in a number of planned wetland restoration projects has brought the project results directly to the management community. In return, working with users has improved our understanding of their information needs. Basic information on vegetation requirements and establishment ability have proved especially useful. Detailed information on an endangered plant (Dunn, 1982) has been used by the U.S. Fish and Wildlife Service in preparing its recovery plan for salt marsh birds beak. In addition, information on bird (e.g., Boland, 1981) and fish (Nordby, 1982) utilization of wetland habitats is in high demand.

Figure 1

A Conceptual Model of the Dynamics of Southern California Marsh Soils and Plants

Profile of marsh:

MSL

Usual Soil Salinity:	35-45 ppt	30-70 ppt	0-60 ppt
Variability of soil ppt:	nearly constant	moderately variable	highly variable
Factors decreasing soil salinity:	Heavy floods temporarily reduce salinity, but this rarely occurs.	Rainfall leaches soil salts; each rainfall event reduces salinity.	
Importance of reduced salinity:	Cordgrass productivity increases; its range expands.	Seeds germinate; growth is stimulated.	

Cooperating Organizations
California Department of Parks and Recreation
City of San Diego
Port of San Diego
U.S. Fish and Wildlife Service
U.S. Navy

References

BOLAND, J. 1981. Seasonal abundances, habitat utilization, feeding strategies and interspecific competition within a wintering shorebird community and their possible relationships with the latitudinal distribution of shorebird species. M.S. thesis, Biology, San Diego State University.

DUNN, P. V. In press. Considerations for restoration of an endangered species: salt marsh bird's beak, *Cordylanthus maritimus* spp. *maritimus*. In *Proc., Workshop on wetland restoration and enhancement in California*, M. Josselyn, ed. Tiburon Center for Environmental Studies. California State University, February 1982. (Abstract of a poster).

NORDBY, C. In press. Fish utilization of Tijuana Estuary: applications for wetland restoration. In *Proc., Workshop on wetland restoration and enhancement in California*, M. Josselyn, ed. Tiburon Center for Environmental Studies. California State University, February 1982. (Abstract of a poster).

ZEDLER, J. B. In *Salt marsh restoration: A guidebook for southern California*. (In prep.).

ZEDLER, J. B. 1981. The San Diego marsh before/after the 1980 flood. Environment Southwest 495:20-22.

ZEDLER, J. B. In press. 1982. Wastewater input to coastal wetlands: management concerns. In *Proc., Workshop in ecological consideration in wetlands used for wastewater treatment*. U.S. Fish and Wildlife Service. Workshop at University of Massachusetts, Amherst, June 1982.

ZEDLER, J. B. 1982. The ecology of southern California coastal salt marshes: a community profile. FWS/OBS-81/54. U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C.

ZEDLER, J. B., JOSSELYN, M., AND ONUF, C. In press. Restoration techniques, research, and monitoring: vegetation. In *Proc., Workshop on wetland restoration and enhancement in California*, M. Josselyn, ed. Tiburon Center for Environmental Studies. California State University, February 1982.

ZEDLER, J. B. In press. Freshwater impacts in normally hypersaline marshes. Estuaries.

Publications

BOLAND, J. 1981. Seasonal abundances, habitat utilization, feeding strategies and interspecific competition within a wintering shorebird community and their possible relationships with the latitudinal distribution of shorebird species. M.S. thesis, Biology, San Diego State University.

DUNN, P. V. In press. Considerations for restoration of an endangered species: salt marsh bird's beak, *Cordylanthus maritimus* spp. *maritimus*. In *Proc., Workshop on wetland restoration and enhancement in California*, M. Josselyn, ed. Tiburon Center for Environmental Studies. California State University, February 1982. (Abstract of a poster).

NORDBY, C. In press. Fish utilization of Tijuana Estuary: applications for wetland restoration. In *Proc., Workshop on wetland restoration and enhancement in California*, M. Josselyn, ed. Tiburon Center for Environmental Studies. California State University, February 1982. (Abstract of a poster).

WILLIAMS, P. 1979. Detritus utilization by *Mytilus edulis*. M.S. thesis, San Diego State University.

WILLIAMS, P. 1981. Detritus utilization by *Mytilus edulis*. Estuarine and Coastal Shelf Science 12:739-746.

WINFIELD, T. 1980. Dynamics of carbon and nitrogen in a southern California salt marsh. Ph.D. thesis, San Diego State University and the University of California, Riverside.

ZEDLER, J. November 1980. Arid region wetlands: susceptibility to disturbance. Estuaries 4:262. Presented at Estuarine Research Federation biennial meeting, Gleneden Beach, Oregon. (Abstract).

ZEDLER, J. B. In *Salt marsh restoration: A guidebook for southern California*. (In prep.).

ZEDLER, J. B. 1980. Algal mat productivity: comparisons in a salt marsh. Estuaries 3:122-131.

ZEDLER, J. B. 1981. The San Diego marsh before/after the 1980 flood. Environment Southwest 495:20-22.

ZEDLER, J. B. 1982. Salt marsh algal mat composition: spatial and temporal comparisons. Bull. Southern California Acad. Sci. 81:41-50.

ZEDLER, J. B. 1982. Salt marsh vegetation: examples from the Tijuana Estuary. Report No. E-CSGCP-003. California Sea Grant College Program, La Jolla, California.

ZEDLER, J. B. In press. 1982. Wastewater input to coastal wetlands: management

concerns. In *Proc., Workshop in ecological consideration in wetlands used for waste-water treatment.* U.S. Fish and Wildlife Service. Workshop at University of Massachusetts, Amherst, June 1982.
ZEDLER, J. B. 1982. The ecology of southern California coastal salt marshes: a community profile. FWS/OBS-81/54. U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C.
ZEDLER, J. B., JOSSELYN, M., AND ONUF, C. In press. Restoration techniques, research, and monitoring: vegetation. In *Proc., Workshop on wetland restoration and enhancement in California,* M. Josselyn, ed. Tiburon Center for Environmental Studies. California State University, February 1982.
ZEDLER, J. B., WINFIELD, T., AND WILLIAMS, P. 1980. Salt marsh productivity with natural and altered tidal circulation. Oecologia 44:236-240.
ZEDLER, J. B. In press. Freshwater impacts in normally hypersaline marshes. Estuaries.

COASTAL WETLANDS MANAGEMENT: APPLICATION OF BIOLOGICAL CRITERIA

University of California, Santa Barbara
R/CZ-52
1980-82

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

During the last 2 years, we have completed most of the major analyses of our research on the responses of the Mugu Lagoon coastal wetland to the major perturbations of storm-caused sedimentation. Because of the unexpectedly great magnitude of these events, the analyses now encompass major morphological alterations of the lagoon, a second aspect of our proposed research. We continue the third section of our project, the evaluation of increased tidal flushing as a technique for the enhancement of coastal wetlands as bird habitats. We are now in the process of subjecting the full data set (censuses of 20 sites, 24 times each year for 6 years) to an analysis of what habitat characteristics govern the kinds and numbers of water-related birds that use the different areas.

The bottom of Mugu Lagoon differed in substrate texture depending on location, but was predominantly sandy until the storm of February 1978. Thereafter it was uniformly muddy, except in the entrance channel and the landward extremities of the lagoon. There was little change in primary productivity; however the change in photosynthetic pigments suggested a switch from an assemblage of primary producers dominated by diatoms to one dominated by blue-green algae. Also, benthic community respiration increased to the extent that the benthic community no longer was strongly autotrophic. Rather, it produced barely as much as was consumed in place. Macroalgae have become more abundant over more of the year. Eelgrass is much reduced, especially in deeper water.

In 1980 we reported a preliminary analysis of the effect of the major storms in 1978 and 1980 on the growth of *Salicornia virginica*, the dominant vascular plant of the salt marsh at Mugu Lagoon. Based on the biomass of green growing tips harvested at the time of peak standing crop in 1977, 1978, 1979, and 1980 we concluded that flooding led to stimulation of plant growth in the growing season after the flood but the effect did not persist to the next growing season. (This short-term stimulation of productivity was presumably caused by the leaching of salts from the marsh soil or addition of nutrients.) On that basis we predicted a reduction in biomass from the 1980 major storm year to 1981, a minor storm year. After the 1981 harvest we were able to carry out a much more thorough analysis, taking location into account. The results indicate a more complex response than did our preliminary analysis (and, incidentally, proved wrong our prediction of a reduction in biomass from 1980 to 1981). The more important effect evident in the analysis of variance is the highly significant interaction between location and year (illustrated in figure 1, top). When each year is depicted as a linear regression of biomass on sample location, the interaction appears as a unidirectional counterclockwise rotation from year 1 to year 4, indicating a gradual shift in the distribution of biomass away from the mouth of the lagoon. In the plots of the individual location averages (n = 5 for each location) for each year (figure 1, bottom), it can be seen that between years 1 and 4 the biomass of growing tips has decreased from 291 to 115 gdw.m^{-2} at location 1, closest to the mouth, whereas at location 6, farthest from the mouth, biomass has increased from 70 to 140 gdw.m^{-2}. This persistent unidirectional change over time suggests a successional process. Our interpretation is that the deposition of new, fine sediments on what had been a well-drained, relatively sandy substrate near the mouth has made it less suitable for marsh plant growth, whereas deposition on previously waterlogged, fine sediments away from the mouth actually have been an improvement by raising the marsh surface slightly, thus reducing waterlogging and allowing better aeration of roots. In contrast to the persistent shift in the distribution of biomass away from the mouth of the lagoon over time, all of the year-to-year variation for the marsh as a whole is accounted for by the deviation between year 2 (1979) and the other years. Our earlier interpretation of short-term stimulation of growth would have required year 4 to be lower as well. These results were reported at the Sixth Biennial International Estuarine Research Conference, 1-6 November 1981.

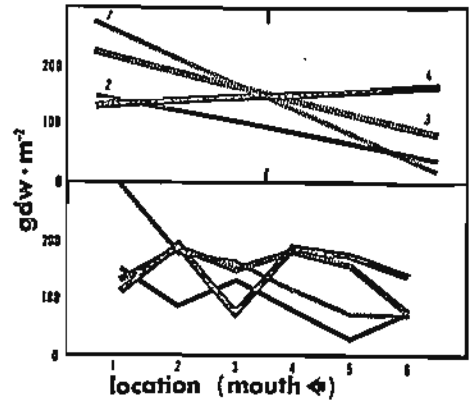


Figure 1. The biomass of green growing tips of *Salicornia virginica* at different distances from the mouth of Mugu Lagoon in the 4 years of the study (1 = 1978 to 4 = 1981, gdw = grams dry weight). Top: each year plotted as a linear regression. The overall yearly means are above the vertical bar on the x-axis. Bottom: the individual location means (n = 5) plotted for each year.

Our studies are revealing that storms of similarly large magnitudes will have drastically different effects, depending on the sediment load of waters actually reaching the study site. Peterson (1975) made his first observations at Mugu Lagoon in 1969 by observing the rapid recovery of molluscs and echinoderms from the major storm of January 1969. Because those marine animals least tolerant of reductions in salinity below normal were low in density in his first collections, increased rapidly, and then stabilized at a much higher density, he interpreted that a reduction in salinity caused by floodwaters had been responsible for the effects on molluscs and echinoderms. He reported no evidence of sedimentation. We witnessed the effects of the next major storm at Mugu Lagoon in February 1978. However, in contrast to 1969, vast amounts of fine-textured new sediments were deposited everywhere in the lagoon. In the entrance channel they remained on the surface only briefly, but in the main body of the lagoon they stayed. On the average, 13 cm of sediment was deposited in subtidal areas. Also in contrast to 1969, we are observing long persistence of effects on the biota. Another major storm, depositing another 6 cm of fresh sediments, occurred in February 1980. The timing of these two major natural environmental perturbations provided us a superb opportunity to analyze rigorously the biotic responses to normally infrequent extreme events. We have one full year of observations before and after each storm, plus a subsequent year of observations for most groups of organisms. The symmetrical sequence of minor and major storm years for the 5 years of study (minor-major-minor-major-minor) from February 1977 to January 1982 allowed clear discrimination between short-term effects (comparisons between adjacent years, i.e., years of different kinds) and persistent effects (comparisons between 1 year and subsequent years of the same kind, i.e., does part of the short-term, or difference between unlike adjacent years, carry over into the next year, similar to the first in terms of the occurrence of storms?). By way of illustration, the significant differences between years in the abundance of fish are as follows: Year 1 > 2 < 3 > 4 < 5. In other words, numbers of fish decline in the years of major storms and increase in the following minor storm year, a clear case of short-term effect. However, in addition, Year 1 > Years 3 and 5, indicating that some part of the short-term declines of the major storms carry over into subsequent minor storm years, that is, effects persist.

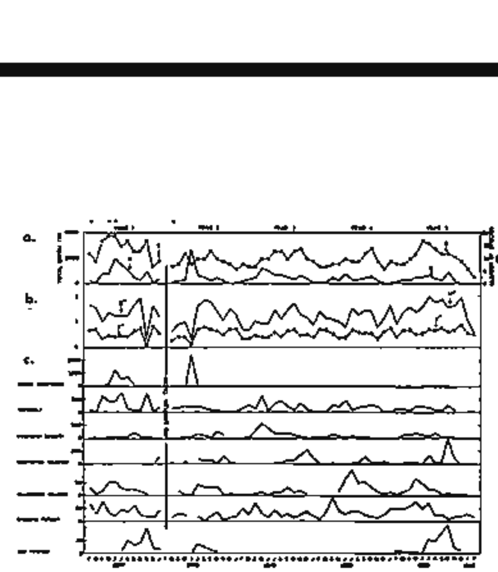


Figure 2. Monthly statistics for the total catch of fish from four sites in the eastern arm of Mugu Lagoon, February 1977 to February 1982. a. Total abundance (N) (left axis) and number of species (S) (right axis). b. Shannon-Weaver index of diversity $H'' = -\Sigma \frac{n_i}{N} \ln(\frac{n_i}{N})$, where n_i is the abundance of the i'th species, and evenness $J = H/\ln S$. c. The number of individuals of the common species caught each month during the study. *Samples not collected at Site 1 in June 1977; Site 2 in February, May, June 1977; and Site 4 in March 1978. Catches for these months were deleted for those sites in all other years for the statistical analyses.

For animals, our most complete information is on the effects of the storms on fish. Our analysis of the dynamics of the fish community of Mugu Lagoon is from monthly catches by beach seine within the eastern arm of the lagoon over 4 years. Most of the annual changes in the populations of fish could be explained by the major storms of Years 2 and 4 (figure 2). As discussed earlier in the description of the analytical procedure, the storms caused both short-term and persistent effects on the total abundance of fish in the lagoon. This was also true for the number of species. All catch statistics with the exception of Shannon-Weaver evenness are down in year 4 compared to year 1 (figure 3a and b). Total number and number of species caught each year have been 8421, 5873, 6002, and 3881 and 36, 20, 23, and 19 respectively, from year 1 to year 4. Shannon-Weaver diversity (H") and evenness (J") were highest at the end of the study (figure 3b). Both of these measures take into account the relative abundance of species and are higher for more even distribution of individuals among species. Thus, the fact that the two dominant species of Year 1, topsmelt (*Atherinops affinis*) and shiner surfperch (*Cymatogaster aggregatus*), suffered much heavier reductions in number than the other common species (figure 3c) accounts for the difference in response of H" and J" compared to abundance and number of species. Other features of the storm-related effects were 1) bottom-dwelling species changed little despite drastic changes in substrate texture; 2) species associated with eilgrass beds were strongly yet differently affected depending on their depth preference, e.g., bay pipefish, *Syngnathus leptorhynchus* almost disappeared with the instantaneous burial of most shallow-water eelgrass and then recovered at a different location where a new bed developed in shallow water; shiner surfperch declined less abruptly but did not recover, paralleling the deep-water eelgrass' gradual deterioration and lack of recovery; 3) species that spend the majority of their time in the water column were adversely affected to a greater extent than bottom-dwelling species, probably in response to the 38% decrease in the low-tide volume of the lagoon.

Because the four sampling sites had different characteristics at the beginning of the study and were affected differentially by the storms (table 1), we have been able to sort out much of the cause and effect in the observed changes in the fish fauna as a whole. The gradual increase in the proportion of total catch for site 1 at the expense of sites 2 and 3 but not site 4 (figure 3c) is consistent with the assessment of physical changes to the sites. Apparently the short-term destruction of food resources was not instrumental in causing the declines of the major storm years because there was no difference in catches between first and second halves of major and minor storm years. Since dense populations of food organisms were re-established within 6 months of the major storms, declines because of food reduction by major storms would have been revealed by these comparisons. Instead, the storm-related effects appear to be persistent and additive (see the annual catches by number and number of species in the previous paragraph). This suggests that a permanent change in lagoon morphology is the primary determinant of the characteristics. On the basis of the gross qualitative changes in bottom characteristics, we predicted that we would see major changes in demersal fish populations, with mud-lovers increasing dramatically and sandy-bottom associates decreasing correspondingly. We did not expect changes in the total abundance of pelagic fishes, although with the elimination of eelgrass beds the relative abundances of different pelagic species would change. Contrary to our expectations, we have not witnessed major increases in the mud-lovers, and the overwhelming change is the reduction in the abundance of the pelagic forms (figure 3a). Totals over the 4 years have declined from 6905, 4733, 3262, to 2604. Abundance in year 4 is three-eighths of year 1. Another observation is that the overwhelming numerical dominants of year 1 have suffered bigger declines than the subdominants.

The analyses for invertebrates and birds are incomplete at this time. However, available information indicates that effects were differential within and between species of bivalves depending on location; the effects being less in the sand channel and on species with higher rates of growth and reproduction. Small, vertically migrating crustaceans were reduced in abundance only briefly, but the dominant species remain different from what they were before the storms. Sand dollars were absent from the sand channel for 4 years, instead of recruiting immediately as in 1969. Shorebirds that feed preferentially in muddy areas have become more common since the storms.

Apparently, the major sedimentation of the 1978 and 1980 storms and its effects on the biota of the eastern arm of Mugu Lagoon are unprecedented, and it is not because scientists weren't there to observe them, nor because major storms did not occur. Biological research has been carried out there every year since 1962. Bigger storms than 1978 or 1980 occurred in 1962 and 1969. No mention was made of sedimentation in the eastern arm of Mugu Lagoon until 1978.

This report began by drawing a contrast in the effects of similar, major storms in 1969 versus 1978 and 1980: short-term effects on the biota in the absence of sedimentation in 1969, long-term effects and major sedimentation in the later storms. We discuss four possible causes of the change in severity of storm-related effects for its relevance to the analysis of potential effects in other systems. 1) If storms coincide with neap tides, there will be no effect. The volume of sediment-laden water will be too small to cause an effect. 2) In 1978 the February storm had been preceded by the fourth wettest January in 32 years of meteorological observations at Pt. Mugu Naval Air Staion, which in turn followed 3 years of subnormal precipitation. It is possible that a watershed will be more liable to erode when it is already close to saturation. The susceptibility would be aggravated by the poor condition of the vegetation after sustained drought. 3) Large-scale residential and commercial development of the upper parts of the watershed have preempted the valley bottoms and forced citrus groves and subsequent residential development onto steep slopes. If this activity has been extensive enough and concentrated in the last decade, the accelerated erosion might account for increased sedimentation downstream. 4) The central basin was dredged 30 feet deep to provide the fill for the construction of the naval air station in the 1940s. In 1961, it was dredged to a depth of 9 m. Deposition in this basin until it was filled would have buffered the eastern arm from siltation. Apparently this buffering capacity was exceeded during the 1978 storm.

Tide records for the storm dates indicate that spring tides are a necessary but not a sufficient condition for major effects in the eastern arm. The 1978 and 1980 storms both coincided with spring tides, but so did the 1969 storm, without apparent effect. We have no data to test the long-drought-then-presaturation hypothesis. Examination of aerial photographs of the upper watershed of Calleguas Creek, the major inlet stream, indicated that large tracts of hilly terrain were being developed in 1979. Comparisons with the USGS topographic sheet for the same area showed that 25% had been developed by 1947, another 15% was developed in the 22 years leading to 1969, and the remaining 60% of the development of hillsides has occurred since 1969. The great expanse of bare hillsides, evident in the 1979 photographs, certainly contributed heavily to the sediment load carried to the lagoon. Similar activities are common in most of the coastal watersheds of this region. As residential and commercial development preempt the valley bottoms, agriculture, especially citrus and avocado groves, are pushed up the hillsides. Examination of aerial photographs of the lagoon itself indicate a minor delta in the central basin as late as March 1977 and virtually complete filling of the central basin by May 1978. The only remaining subtidal parts are relatively narrow channels radiating to the extremities of the lagoon west, north (Calleguas Creek), and east.

On the basis of these observations, we conclude that at least the proximate cause of the unprecedented effects of the 1978 and 1980 storms, despite more severe storms occurring in 1962 and 1969, is that the storms not only coincided with spring tides but also the sink for sediments provided by the central basis was filled before the end of the 1978 storm. The climatic pattern immediately preceding the 1978 storm and changes in land use in the upper reaches of the watershed may have aggravated erosional processes, thereby augmenting the supply of sediments; however, these probably were not the main causes of the major changes in the eastern arm.

We can summarize the results of our work in the form of a general projection for the coastal wetlands of this region. The rare episodes of major sedimentation that occur when extremely heavy rains coincide with spring tides should produce a step-wise shoaling of these small coastal lagoons. According to our observations, each episode will cause a sharp reduction in the abundance of fishes, followed by an increase that will not achieve previous levels. Pelagic species and perhaps more specialized species will decline the most. The deepest parts of the lagoons will fill the fastest. Land use in the surrounding watershed will influence the severity of these effects. All of these factors should be considered in the management of these systems.

It is obvious from this brief summary of a broad array of data that the effects of major storms on the biota of Mugu Lagoon have been major and diverse. Of greatest significance for the management of coastal wetlands is the fact that some effects have persisted as long as our study and show every evidence of persisting longer. According to our interpretation, these long-lasting effects are linked to changes of lagoon morphology caused by sediment deposition. Others concerned with the management or preservation of coastal wetlands are aware of the threat posed by sedimentation. Here, we have provided a thorough documentation of the effects on the biota and some of the causal mechanisms. Knowing the basic physical characteristics and land use in coastal watersheds and the basic morphology and biology of their associated wetlands, it should be possible to anticipate future changes in the biota of other wetlands of this region. This should provide fruitful direction for management. Clearly, control of sediment sources would be most desirable. In the absence of effective sediment controls, other avenues to follow are to limit programs of resource enhancement to wetlands isolated from floodways, or to divert inlet streams, preferably only during major floods. The latter would be feasible only in conjunction with a major flood control project.

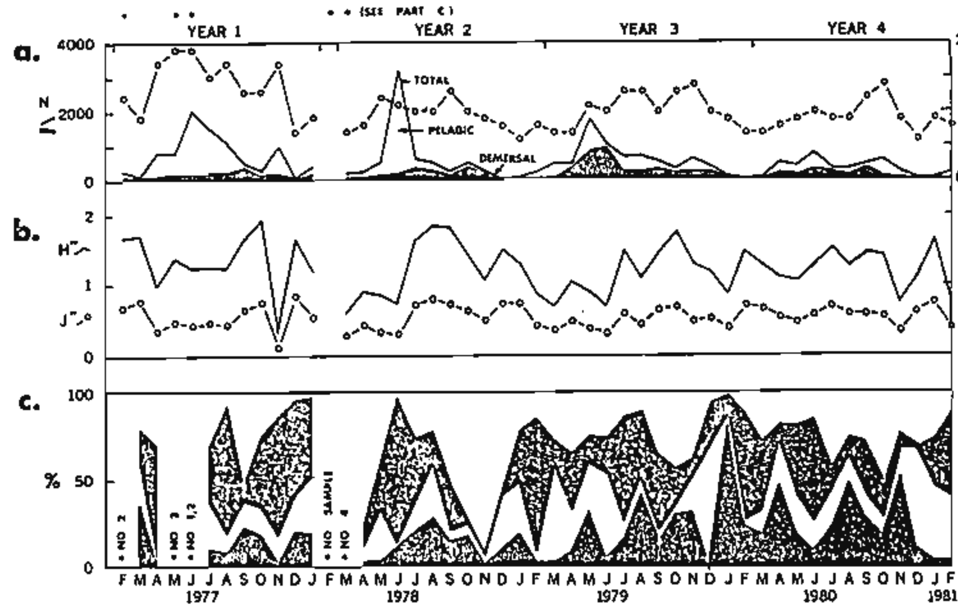


Figure 3. Monthly statistics for the total catch of fishes from four sites in the eastern arm of Mugu Lagoon, February 1977 to February 1981. a. Abundance of demersal and pelagic species, total abundance (N) and number of species (S). b. Shannon-Weaver index of diversity $H' = -\Sigma \frac{n_i}{N} \ln (\frac{n_i}{N})$, where n_i is the abundance of the i'th species, and evenness $J = H/\ln S$. c. The percent contribution of different sites to the total catch in each month. The sites are displayed alternately in black and white from 1 on the bottom to 4 on the top.

Cooperating Organizations
U. S. Naval Air Station, Pt. Mugu

References

PETERSON, C. H. 1975. Stability of species and of community for the benthos of two lagoons. Ecology 56:958-965.
ZEDLER, J. B. 1982. The ecology of southern California coastal salt marshes: a community profile. FWS/OBS-81/54. U.S. Fish and Wildlife Service, Biological Services Program, Washington, D.C.

Publications

CHAPMAN, J. W., ONUF, C. P., AND QUAMMEN, M. L. In press. Effects of fish predation on peracarid crustaceans in Mugu Lagoon, California. In *Proc., Third Technical Workshop on Fish Food Habits Studies.*
HOLMES, R. W. AND MAHALL, B. E. 1982. Preliminary observations on the effects of flooding and desiccation upon the net photosynthetic rates of high intertidal estuarine sediments. Limnology and Oceanography 27:954-958.
HOLMES, R. W., WILSON, C. J., AND AMSPOKER, M. C. 1981. Techniques for preparing permanent preparation of cleaned & uncleaned diatoms using Cumar R-9, a cumarone-indene resin. Bacillaria 4:21-27.
ONUF, C. P. In press. Science and plans: California's coastal wetlands. In *Coastal Zone '80.* American Society of Civil Engineers, New York. Also presented as a paper at Coastal Zone '80, Hollywood, Florida, November 1980.
PETERSON, C. H. AND ANDRE, S. V. 1980. An experimental analysis of interspecific competition among marine filter feeders in a soft-sediment environment. Ecology 61:129-139.
PETERSON, C. H. AND QUAMMEN, M. L. In press. Siphon nipping: its importance to small fishes and its habitat-specific impact on growth of the bivalve, *Protothaca staminea* in a southern California lagoon. Journal of Experimental Marine Biology and Ecology.
PETERSON, C. H. In press. Interactions between two infaunal bivalves, *Chione undatella* and *Protothaca staminea*, and two potential enemies, a fouling organism, *Crepidula onyx*, and a predator, *Cancer anthonyi.* Journal of Experimental Marine Biology and Ecology.
QUAMMEN, M. L. December, 1980. The impact of predation by shorebirds, benthic feeding fish and a crab on the shallow living invertebrates in intertidal mudflats of two Southern California lagoons. Ph.D. thesis, Biology, University of California, Irvine.
QUAMMEN, M. L. In press. Use of exclosures in studies of predation by shorebirds on intertidal mudflats. In *The Auk.*
QUAMMEN, M. L. In press. The influence of subtle substrate differences on feeding by shorebirds on intertidal mudflats. Marine Biology.
SHAFFER, G. P. 1982. Primary production of the benthic microflora in a southern California estuary. M. A. thesis, University of California, Santa Barbara.
WILSON, C. J. 1980. The effect of substrate type on the survival and recruitment of epibenthic diatoms in Mugu Lagoon, California. M.A. thesis, Biology, University of California, Santa Barbara.
ZEDLER, J. B., JOSSELYN, M., AND ONUF, C. In press. Restoration techniques, research, and monitoring: vegetation. In *Proc., Workshop on wetland restoration and enhancement in California*, M. Josselyn, ed. Tiburon Center for Environmental Studies. California State University, February 1982.

PHOSPHORITES ALONG THE CENTRAL CALIFORNIA CONTINENTAL MARGIN

San Jose State University
R/CZ-54
1980-81

Henry T. Mullins

Phosphorites, widely used as a source of agricultural fertilizers and a potential source of uranium, are common in today's ocean along continental margins and isolated seamounts (figure 1). However, most of these deposits appear to be relicts of the Miocene epoch (5-25 million years ago) as contemporary phosphorites are known only from the continental margins of Peru (Burnett, 1977), Namibia (Baturin *et al.*, 1972), and Australia (O'Brien and Veeh, 1980). On land, major phosphorite deposits ranging in age from 22 hundred to 14 million years, are known from a wide variety of locations (Cook and McElhinny, 1979; Sheldon, 1981).

Here in California, phosphorites of Miocene age occur both on land and in offshore areas (Wilson and Mero, 1966; Dickert, 1966; Roberts, 1981). Phosphorites off the shore of southern California have been studied extensively (Deitz *et al.*, 1942; Emery, 1960; Mero, 1961), whereas those off the shore of central California have not previously been examined in any detail. The purpose of our study is to evaluate the distribution, mineralogy, petrography, geochemistry, age, and resource potential of phosphorites offshore central California.

Distribution of Phosphorites Offshore Central California

When we began our study, only a few reports of phosphorites offshore central California existed in the literature (Hanna,1952; Emery and Uchupi, 1963; Greene, 1977). These papers reported occurrences of phosphorites seaward of Cordell Bank, Pescadero Point, Monterey Bay, and Point Sur. We decided to concentrate our sampling efforts in these areas as well as off Cape San Martin where we noticed two prominent knolls on the sea floor. We spent 20 days at sea dredging and mapping the distribution of phosphorites offshore central California. Our results (figure 2) indicate 1) that significant concentrations of phosphorites exist offshore Point Sur (Sur Knoll) and Cape San Martin (Twin Knolls), 2) that minor phosphorites are present offshore Pescadero Point, and 3) that phosphorites are not common near Cordell Bank nor in Monterey Bay. The overall distribution of phosphorites, however, appears patchy. Most of our field work concentrated on the Point Sur-Cape San Martin area. The bathymetry and location of dredge stations for Sur Knoll and Twin Knolls are shown in figures 3 and 4 and photographs of typical dredge hauls in figures 5A and B. Note that these phosphorites were recovered from relatively deep water (800-1400 m). We have not yet prepared sample locality maps for the Pescadero area.

Mineralogy

Mineralogy of phosphorite samples from Twin Knolls, Sur Knoll, and off Pescadero was determined by standard X-ray diffraction techniques (figure 6). All samples are dominated by the mineral francolite, a carbonate fluorapatite ($Ca_5[PO_4, CO_3]_3[F, OH]$). Detrital grains of quartz, feldspar, and rock fragments, as well as authigenic glauconite constitute secondary minerals in most of the samples. Chert (SiO_2) and dolomite (Ca $MgCO_3$) were also found associated with phosphorites at Twin Knolls.

Petrography

Approximately 50 phosphorite samples were thin sectioned and examined by petrographic microscope. To date, we have completed only cursory petrographic examination; detailed studies are now underway. Our preliminary observations indicate that all the phosphorites offshore central California are primary, and not the result of limestone replacement. These phosphorites, however, do appear to have undergone multiple episodes of diagenetic phosphatization and reworking and concentration by currents, commonly resulting in a conglomeratic fabric. Most of the samples that we have examined are

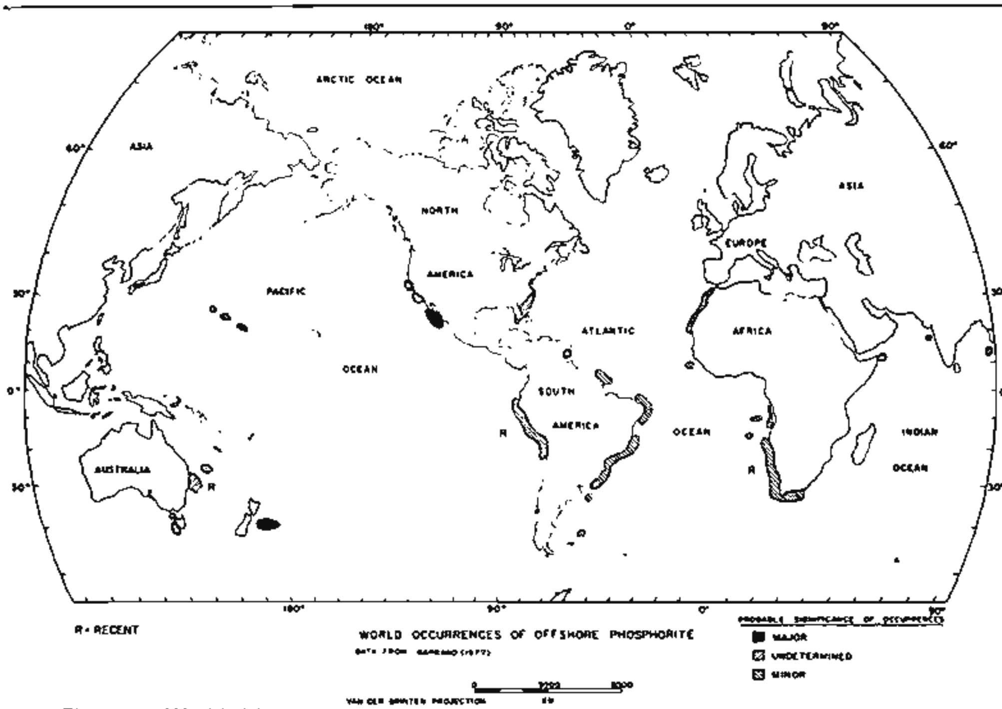


Figure 1. Worldwide distribution of offshore phosphorites.

pelloidal or oolitic phosphorites. "Ooliths" are very common (figure 5, C and D) and typically show concentric laminations of apatite around a nucleus of quartz, glauconite, or tests of foraminifera. The surrounding matrix is fine-grained, isotropic apatite that may represent a primary interstitial precipitate.

Geochemistry

We have analyzed 41 rock samples from our dredge hauls for their phosphorous content (P_2O_5) by spectrophotometric techniques. Our results indicate that the central California phosphorites are rich in phosphorous containing 14-31% (P_2O_5) (table 1). In addition, we have also had elemental analyses completed on nine samples from central California and two from southern California[1] by X-ray fluorescence (table 2), done commercially at Northern California Analytical Labs, and four samples from central California by neutron activation analysis (table 3), done at Lawrence-Berkeley Labs. The results from these analyses have just recently arrived, and we have not had an opportunity to analyze them completely. However, one can readily evaluate the uranium concentrations in the central California samples which range from 47 to 170 ppm with an average value of 92 ppm. This average value is slightly lower than the average phosphorite which has 105 ppm uranium (Altschuler, 1980).

Age

The age of the phosphorites offshore central California is not presently known. Three samples have recently been sent to Dr. W. C. Burnett at Florida State University for uranium-series dating, which will tell us whether or not our samples are contemporary (i.e., less than 800,000 years old). If these samples are greater than 800,000 years

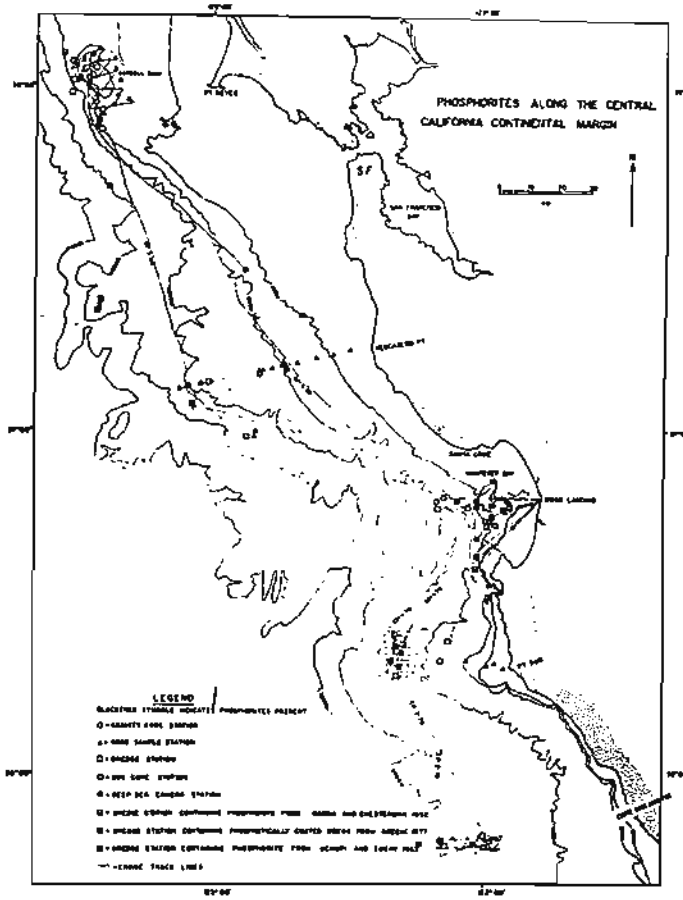


Figure 2. Generalized bathymetry, cruise-track lines, and location of bottom samples from central California continental margin.

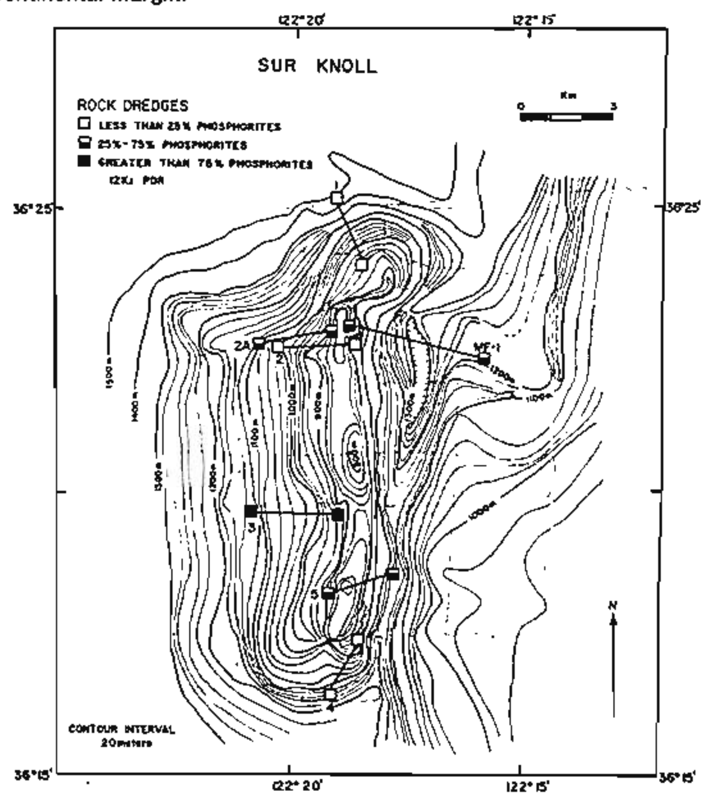


Figure 3. Bathymetry and dredge sample locations for Sur Knoll off Point Sur. See figure 2 for regional location.

[1] Samples from southern California borderland provided by Don Gorsline of USC.

old, they will have to be dated by foraminiferal or diatom biostratigraphy. Once we receive the results from Dr. Burnett, we will decide if biostratigraphic analysis is needed. Our suspicion is that these phosphorites are not contemporary, but rather Miocene in age, similar to on-land phosphorites in California (Dickert, 1966).

Resource Assessment

Based on our P_2O_5 data (table 1), we know that the offshore central California phosphorites are low to medium grade deposits (24-31% P_2O_5 is considered medium, and greater than 31% P_2O_5 high; Roberts and Vercoutere, 1981). The offshore central California phosphorites have a range of P_2O_5 values of 14.0-31.0% with an average value of 24.1% (table 1). We also know that these phosphorites are slightly depleted in uranium, although such values (tables 2 and 3) are fairly typical.

Two other important points must be considered in any resource assessment: 1) concentration/volumes and 2) accessibility. We do not have any data on concentration or calculated volumes. The best way to approach this question is with deep-sea photographs. Unfortunately, we have had little success at obtaining bottom photographs of phosphorites offshore central California. Our deep-sea camera is now working well, and we will make one final attempt at deep-sea photography in April 1982.

Although phosphorites offshore central California appear to be locally concentrated (figures 2-4) and of medium phosphorous content, it is unlikely that they will be an economical minable resource in the near future for two reasons: 1) their depth of occurrence is 800-1400 m, much deeper than other known deposits, particularly offshore southern California (table 4); and 2) extensive phosphorite deposits exist on land in California (Dickert, 1966; Roberts, 1981). It seems to us that phosphorites found on land or in shallower offshore waters would have more resource potential than those offshore central California.

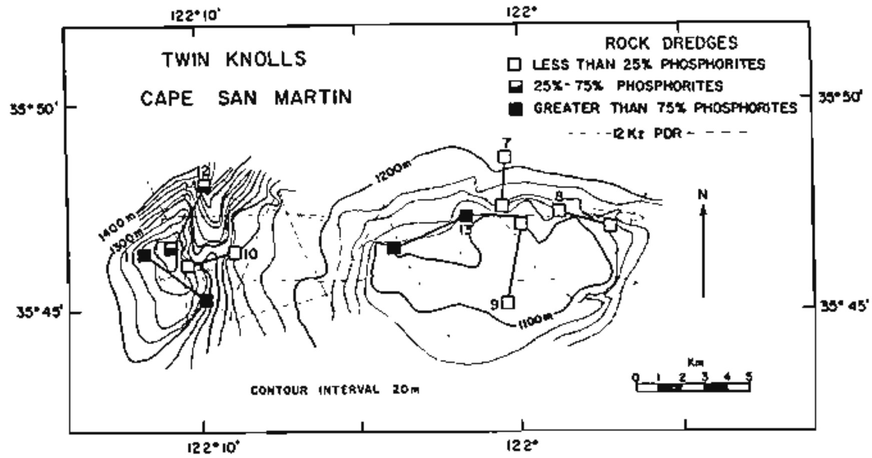


Figure 4. Bathymetry and dredge sample locations for Twin Knolls off Cape San Martin. See figure 2 for regional location.

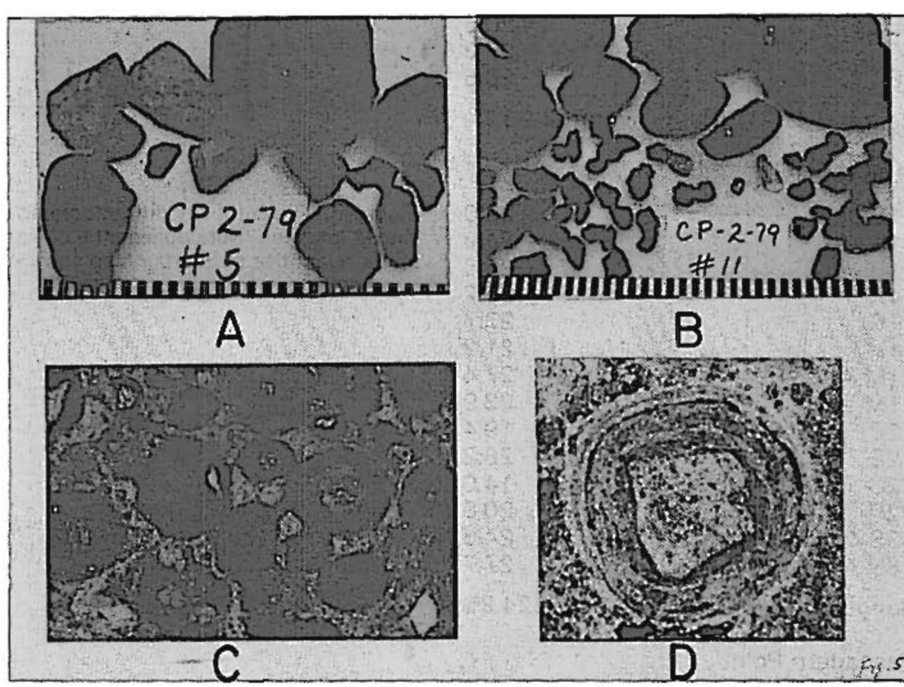


Figure 5. (A and B) Photographs of rock dredge hauls from Sur Knoll and Twin Knolls offshore central California. Dark brown slabs and nodules are phosphorites. Lighter color rocks are mostly unphosphatized Pliocene (?) siltstones. Scale is in centimeters. Sample numbers correspond to dredge sites in figures 3 and 4. (C and D) Thin section photomicrographs of phosphorites offshore central California. Note dominance of concentrically laminated "ooliths." D is a closeup of an "oolith" in C. Scale for C — approximately 2 mm across photo. Scale for D — approximately 0.5 mm. Dredge sample 42 from offshore Pescadero Point.

Table 1

P_2O_5 Analyses of Central California Phosphorites

Sample #	P_2O_5%
Sur Knoll	
2A-2	14.3
2A-3	28.0
2A-5	14.5
2A-6	28.0
2F	24.5
3S-1	24.0
3S-2	23.3
3S-6	21.9
3S-7	22.5
3S-8	31.0
3S-9	25.8
3A	24.0
3B	23.4
3C	24.8
3D	22.0
3E	20.6
3G	27.3
4E	26.5
Range: 14.3-31.0%	Average: 23.7%
Twin Knolls	
11S-1	29.0
11A	24.0
11B	25.8
11F	23.2
11G	27.7
11I	21.2
11M-1	27.4
11M-2	28.9
12C	19.4
12E	26.2
12G	14.0
12H	20.8
13S-2	24.5
13N	27.7
Range: 14.0-29.0%	Average: 24.2%
Pescadero Point	
42C	24.3
42D	27.6
42F-E	24.5
42F-M	28.8
42K	24.7
42M-E	25.0
42N	23.5
42P	27.3
42Q-M	27.1
Range: 23.5-28.8%	Average: 25.8%

Range of All Samples: 14.0-31.0%
Average of All Samples: 24.1%

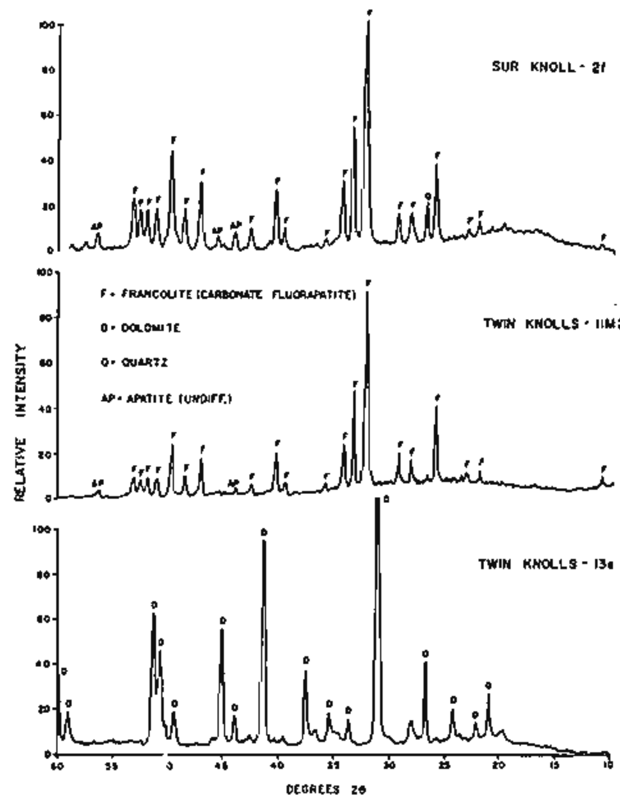


Figure 6. Typical X-ray diffractograms of phosphorites from Sur Knoll (top) and Twin Knolls (middle). Note dominance of francolite and undifferentiated apatite with only minor quantities of quartz. Also shown is a diffractogram (bottom) of an unphosphatized dolostone from Twin Knolls.

Table 2
X-ray Fluorescence Analyses

	Sample Sites										
	Sur Knoll			Twin Knolls			Pescadero			Southern California	
Element *(ppm)	CP-1 #2	CP-2 #3	CP-2 #4E	CP-2 #11M	CP-2 #12-H	CP-2 #13	CP-3 #42C	CP-3 #42F	CP-3 #42FL	SC 14407	SC 14414
Al %	-	1.53	-	-	1.73	1.68	-	0.53	-	-	0.42
As	-	34	-	-	26	-	30	-	12	-	20
Ba	-	210*	-	222*	636*	-	268*	1.80	1.52	218	0.47
Br	64	-	-	16	-	15	-	-	-	-	27
Ca %	0.81	25.81	33.33	31.51	23.37	28.76	33.18	30.57	30.98	34.35	30.49
Cu	122	111	83	52	85	87	136	96	39	-	72
Fe %	4.54	3.51	0.54	2.77	3.45	2.15	1.61	1.10	1.45	1.19	1.85
K %	0.44	-	-	0.61	1.08	1.08	0.48	0.45	0.33	0.34	0.48
Mg %	12.29	1.67	-	-	-	0.67	-	-	-	-	-
Mn	-	322*	-	-	-	-	-	-	-	-	228*
Na %	-	-	-	-	-	0.28	-	-	-	-	-
Ni %	-	-	-	-	-	145	-	-	-	-	-
P %	0.17	10.79	14.08	12.21	9.71	11.38	12.98	12.19	12.27	13.65	12.29
PB	-	-	-	-	8	25	-	-	10	-	-
Rb	11	31	-	28	41	72	22	21	11	13	15
S %	0.52	0.60	-	0.79	0.43	0.80	1.17	1.53	1.39	0.72	1.05
Si %	25.5	7.97	-	3.32	11.26	6.94	4.12	3.51	2.95	1.69	3.31
Sr %	56*	0.17	0.16	0.21	0.15	0.15	0.21	0.25	0.25	0.23	0.22
Ti	53*	0.10	-	-	0.14	0.18	246*	-	-	-	-
U	-	54	47	117	75	82	170	152	119	86	68
V	50	-	-	-	-	229	75	-	-	-	-
Y	-	-	15	77	21	61	81	108	61	16	20
Zn	62	-	223	38	78	125	96	103	45	-	53
Zr	7	98	-	-	138	85	56	57	-	-	59

Table 3

Neutron Activation Analyses

	Sample Sites			
	Sur Knoll		Twin Knolls	
Element (ppm)	3A	2F	11M	12E
Al %	1.48	1.19	0.175	0.250
Ca %	27.4	28.5	30.8	29.0
Na %	1.256	1.095	1.222	1.053
K %	0.99	0.99	0.45	0.82
Sr	1990	1830	2560	2390
Mn	88.1	67.2	45.9	43.7
Dy	3.02	2.93	3.44	5.96
Cu	⩽30	⩽42	⩽53	⩽54
As	16	⩽32	16	17
Mg %	⩽.98	0.81	1.16	1.39
U	~76	~85	~66	~67
Sm	3.04	3.77	3.81	5.29
La	15	33	⩽25	46
Ba	161	114	525	279
Sb	2.9	1.7	1.9	4.2
Ag	⩽2.4	⩽1	1.7	1.9
Sc	4.14	3.05	1.15	1.10
Fe %	3.0	2.71	2.09	3.88
Co	3.4	3.93	1.94	2.40
Cr	104	95.1	66.4	110
Ni	29	⩽18	40	17
Th	2.13	1.80	0.49	0.52
Cs	2.77	2.38	1.22	3.77
Ta	0.33	0.26	0.18	0.17
Hf	1.13	1.03	0.418	0.527
Ce	27.1	21.5	13.7	25.6
Yb	2.15	2.2	2.48	3.78

Table 4

Comparison of Offshore Central California Phosphorites to Selected Other Known Deposits

Location	Depth (m)	Type	P_2O_5	Age	Reference
Central California	800-1400	Primary	14-31	Miocene (?)	This paper
Southern California	75-2200	Primary and replaced	22-29	Middle Miocene	Dietz et al. (1942)
Peru	200-500	Primary	13-29	Recent	Burnett (1977)
Chatham Rise New Zealand	⩽400 m	Replaced	15-25	Early to middle Miocene	Cullen (1980)
Blake Plateau Southeast U.S.	250-1000	Primary and replaced	22-24	Miocene	Manheim et al. (1980)
Namibia, S.W. Africa	50-1000	Primary and replaced	17-33	Miocene and recent	Baturin et al. (1972); Birch (1980)
Baja California, Mexico	25-200	Primary	6-30	Miocene and recent	D'Anglejan (1967); W. C. Burnett (pers. comm.)

Cooperating Organizations
Moss Landing Marine Laboratories
University of California, Berkeley
U.S. Geological Survey

References

ALTSCHULER, Z. S. 1980. The geochemistry of trace elements in marine phosphorites: Part I. Characteristic abundances and enrichment. Spec. Pub. No. 29. Society of Economic Paleontologists and Mineralogists (SEPM).

BATURIN, G. N., *et al.* 1972. Radiometric evidence for recent formation of phosphatic nodules in marine shelf sediments. Mar. Geol. 13:M37-M41.

BIRCH, G. F. 1980. A model of penecontemporaneous phosphatization by diagenetic and authigenic mechanisms from the western margin of southern Africa. Spec. Pub. 29. Society of Economic Paleontologists and Mineralogists (SEPM).

BURNETT, W. C. 1977. Geochemistry and origin of phosphorite deposits from off Peru and Chile. Geol. Soc. Amer. Bull. 88:813-823.

COOK, P. J. AND MCELHINNY, M. W. 1979. A re-evaluation of the spatial and temporal distribution of sedimentary phosphate deposits in the light of plate tectonics. Econ. Geol. 74:315-330.

CULLEN, D. J. 1980. Distribution, composition and age of submarine phosphorites on Chatham Rise, east of New Zealand. Spec. Pub. No. 29. Society of Economic Paleontologists and Mineralogists (SEPM).

D'ANGLEJAN, B. F. 1967. Origin of marine phosphorites off Baja California, Mexico. Mar. Geol. 5:15-44.

DICKERT, P. F. Tertiary phosphatic facies of the coast ranges. Bull. 190. Calif. Div. Mines and Geol.

DIETZ, R. S., EMERY, K. O., AND SHEPARD, F. P. 1942. Phosphorite deposits on the sea-floor off southern California. Geol. Soc. Amer. Bull. 53:815-848.

EMERY, K. O. 1960. In *The sea off southern California.* John Wiley and Sons, Inc., New York.

EMERY, K. O. AND UCHUPI, E. The continental slope between San Francisco, California and Cedros Island, Mexico. Deep-Sea Res. 10:397-447.

GARRAND, L. J. 1977. Offshore phosphorite: world occurrences. U.S. Bureau of Mines. Denver, Colorado.

GREENE, H. G. 1977. Geology of the Monterey Bay region, California. Open-File Rept. 77-718. U. S. Geol. Surv.

HANA, C. D. AND CHESTERMAN, C. W. 1952. Geology of continental slope off central California. Proc. Calif. Acad. Sci. 27:325-374.

MANHEIM, F. T., PRATT, R. M., AND MCFARLIN, P. F. 1980. Composition and origin of phosphorite deposits of the Blake Plateau. Spec. Pub. No. 29. Society of Economic Paleontologists and Mineralogists (SEPM).

MERO, J. L. 1961. Sea floor phosphorite. Calif. Div. Mines and Geol. 14(11):1-12.

O'BRIEN, G. W. AND VEEH, H. H. 1980. Holocene phosphorite on the east Australian continental margin. Nature 288:690-692.

ROBERTS, A. E. 1981. Phosphatic rock localities in California. Open-File Rept. 81-260. U. S. Geol. Surv.

ROBERTS, A. E. AND VERCOUTERE, T. L. 1981. Geology and petrology of the upper Miocene phosphate deposit near New Cuyama, Santa Barbara County, California. Open-File Rept. 81-1037. U. S. Geol. Surv.

WILSON, T. A. AND MERO, J. L. 1966. Economic deposits of the California offshore area. Bull. 190. Calif. Div. Mines and Geol.

Publications

MULLINS, H. T. AND RASCH, R. F. In prep. 1982. Petrography and geochemistry of phosphorites offshore central California. Economic geology.

RASCH, R. F. 1981. Phosphorites offshore of Point Sur and Cape San Martin, California. Cordilleran Section Mtg, Geological Society of America 13(2). (Abstract).

RASCH, R. F. In prep. 1982. Phosphorites offshore central California. M.S. Thesis, Dept. of Geology, San Jose State University.

SALT MARSH RESTORATION: AN ECOLOGICAL EVALUATION OF AN ESTUARINE MITIGATION PROJECT

Humboldt State University
R/CZ-56
1980-81

Roger Barnhart and Milton Boyd

Because 70-80% of California's tidal marshes have been destroyed, the California Coastal Act (Section 30233(b)) now requires mitigation measures to minimize adverse environmental effects for any diking, filling, or dredging. One present mitigation technique is restoration — the rehabilitation and return of part of the ecosystem, formerly altered or removed from wetland production, back to effective wetland productivity. According to Section 30607.1 of the California Coastal Act, restoration is acceptable if an equivalent area is available that provides equal or greater habitat values to the same type and variety of plant and animal species that used the area affected by the diking, filling, or dredging. Simply removing dikes to return tidal flushing has become an acceptable restoration technique, although information is lacking to evaluate the effectiveness of such efforts as a viable mitigation method.

Construction of the Woodley Island Marine Project in Humboldt Bay, California began in August 1979. Humboldt Bay is known as an important embayment in California providing habitat for approximately 96 fish species. Humboldt Bay is also a nursery area for many organisms including English sole, dungeness crab, Pacific herring, and northern anchovy. The Woodley Island project has disrupted approximately 3000 feet of shoreline by dredging of intertidal and subtidal mud flats and filling of the adjacent salt marsh. A mitigation area to replace the lost habitat was selected up Freshwater Slough (see figure 1). The mitigation site is approximately 22 acres which was formerly marginal pasture land. In December 1980, it was returned to tidal flushing by breaching the existing dike.

Vegetation

Vegetation maps of the study site (Park Street Marsh) and control site (Bay Street Marsh) were prepared prior to breaching of the dike surrounding the Park Street site in December 1980 (figures 2 and 3). The control site contained species characteristic of salt marshes surrounding Humboldt Bay, with three species accounting for over 90% of the plant cover: *Salicornia virginica, Distichlis spicata*, and *Spartina foliosa.* The study site at Park Street contained a more complex mixture of plant species that included freshwater marsh species, species characteristic of disturbed grassland (particularly *Deschampsia caespitosa*), and small patches of salt marsh species. These salt marsh species appear to have been growing in areas where brackish water from the adjacent slough intruded through the dike and increased the soil salinity. Following breaching of the dike, a noticeable die-back of the disturbed grassland species began to occur, but this was difficult to describe quantitatively because the same time period corresponded to winter dormancy of all plant species at the site. During the spring and summer months of 1981 (5-9 months after breaching the dike), salt marsh species already established at the study site flourished but did not expand noticeably in areal coverage. The grasses that had grown throughout the former pasture were decaying and were covered by both brown and green filamentous algae, not yet identified. The freshwater marsh at the southwest corner of the study site was little affected by saltwater intrusion. Seasonal growth of cattails (*Typha latifolia*) was evident from spring through summer.

We conclude from these preliminary findings that establishment of salt marsh plant species throughout the restoration site will require considerably longer than one growing season. Even though salt marsh species on the site were observed to flower and set seed during the summer of 1981, germination of the seed and establishment of progeny will not be obvious until summer 1982, at the earliest.

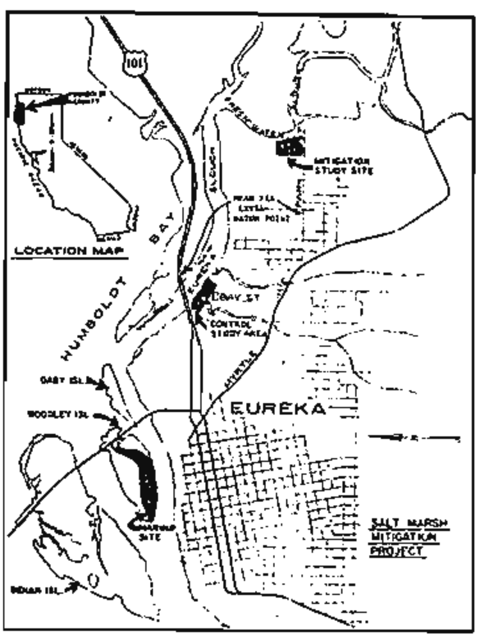


Figure 1. Location map of Woodley Island Marine site, Park Street mitigation study area, and Bay Street control study area.

Salt Marsh Invertebrates

Sampling sites for major species of salt marsh invertebrates were established in January 1981, at both the study and control sites (figures 4 and 5). The two most abundant gastropods at the control site were *Assiminea californica* and *Ovatella myosotis*, detritus-feeding animals found in high numbers at well developed salt marshes around Humboldt Bay. Single specimens of each species were collected only once at the study site, in March 1981, and must be treated as incidental occurrences. The salt marsh amphipod *Orchestia traskiana* was consistently present at the control site but did not begin to appear in abundance at the study site until July and August 1981. Other crustaceans collected at the control site were the isopods *Gnorimosphaeroma oregonensis* and *Armadilloniscus coronocapitalis*.

Gnorimisphaeroma oregonensis began to occur sporadically in samples from the study site from April through August 1981. The most consistently present invertebrate at the study site was the amphipod *Anisogammarus confervicolus*, a species we have collected from the adjacent slough and from other estuarine benthic habitats around Humboldt Bay. It appears that this species was carried into the study site on rising tides and some animals were stranded on decaying vegetation during receding tides. The animals were most abundant at sample stations near the breach and were absent from stations in the southern part of the marsh most distant from the breach. Complete species lists for the control and study sites are presented in table 1.

Species characteristic of estuarine benthic habitats (*Eteone californica, Streblospio benedicti, Polydora ligni, Pseudopolydora kempi, Alderia modesta*) were occasionally encountered at the study site in sediments near the breach in the dike and have also been collected in abundance from the adjacent slough. These findings suggest that species with pelagically dispersed larvae may become established rapidly at lower elevations of the study site. The two salt marsh gastropods brood their young, however, consequently there is less opportunity for rapid dispersal to newly available habitats. It will probably be some time before these two species become established in large numbers at the study site.

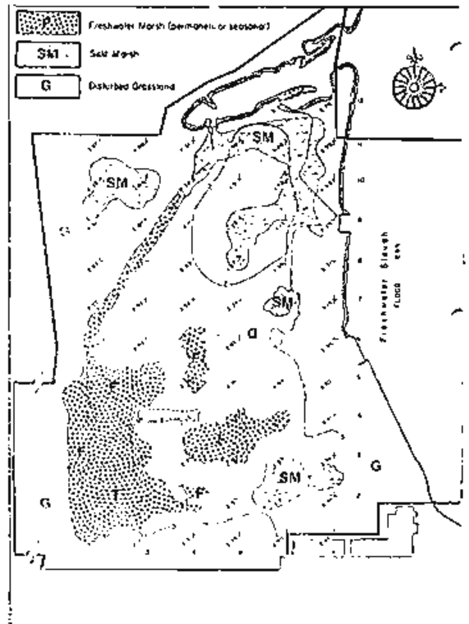


Figure 2. Park Street mitigation study area: habitat map.

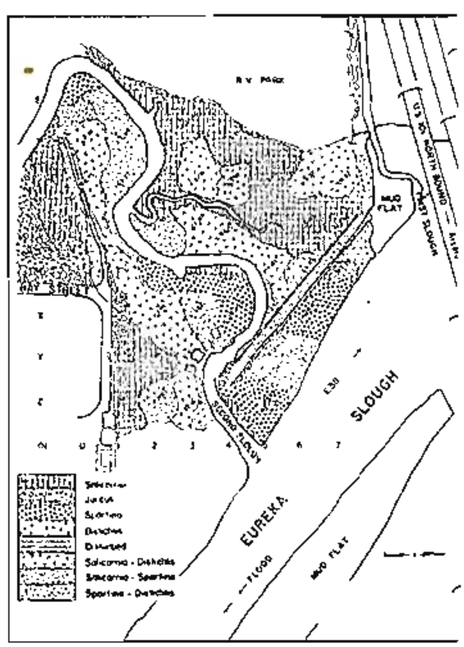


Figure 3. Bay Street control study area: vegetation type map.

In an attempt to objectively compare the invertebrate faunas of the two sites, Jaccard's Coefficient of Similarity was calculated from the species lists of table 1. This coefficient accounts only for the presence or absence of species at the two sites.

$$J = \frac{C}{A + B - C}$$

where C = the number of co-occurring species at the two sites, A = the number of species at one of the sites, and B = the number of species at the other site. Jaccard's coefficient calculated from the species occurrences at the control and study sites is 35.7%, indicating a modest degree of similarity.

It appears that in consonance with the vegetation data, invertebrate populations characteristic of salt marshes surrounding Humboldt Bay are becoming established slowly at the mitigation site. Our data do not allow us to predict how much time will be required for salt marsh invertebrates to become established at the study site, but it will certainly be on the order of years rather than months.

Fish

The fisheries resources of the restoration site were monitored (figures 1 and 6) and the area's abundance of fish, diversity, and degree of use were compared to that of a nearby undisturbed salt marsh (figures 1 and 7) and to the waters adjacent to Woodley Island. Preliminary sampling began in December 1980; the major field effort started in mid-July 1981 and will continue at least thru July 1982. Information derived from this investigation will increase the understanding of how fish use coastal marshlands and will assist in determining future acceptable mitigation sites.

The sampling equipment necessary to meet the research objectives was developed or obtained and tested first. Prior to fish sampling, a grid system was established and elevations at each point determined within both the restoration site and the comparative marsh. The elevation of the comparative marsh averages approximately 1.3 feet higher than the restoration site. Only the highest of spring tides flood the comparative marsh whereas most high tides will at least partially cover the restoration site. Both study areas are covered with dense vegetation, making sampling difficult. Because of the vegetation problem and elevation differences, a diverse sampling program was developed and is still in progress.

The channel created where the dike was breached at the restoration marsh and second slough at the comparative marsh are being sampled for larval and juvenile fishes moving into and out of the marsh areas using a modified channel net with a ½-m plankton net sewn into the center (figures 8 and 9). During sampling the net is staked in place and fished in a stationary position facing the tidal current. A flow meter is also staked adjacent to the net

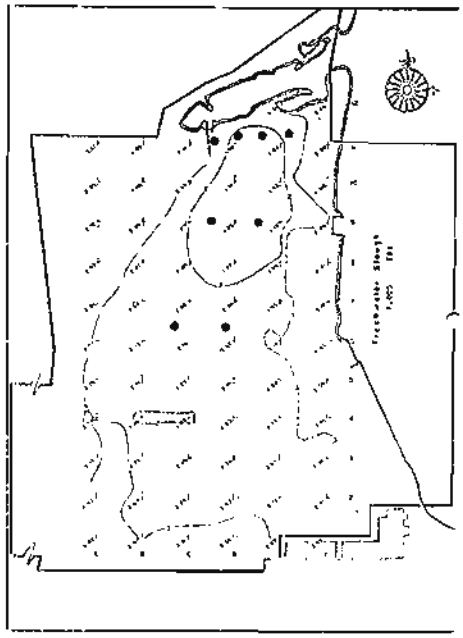


Figure 4. Park Street mitigation study area. Filled circles are sample stations for invertebrates.

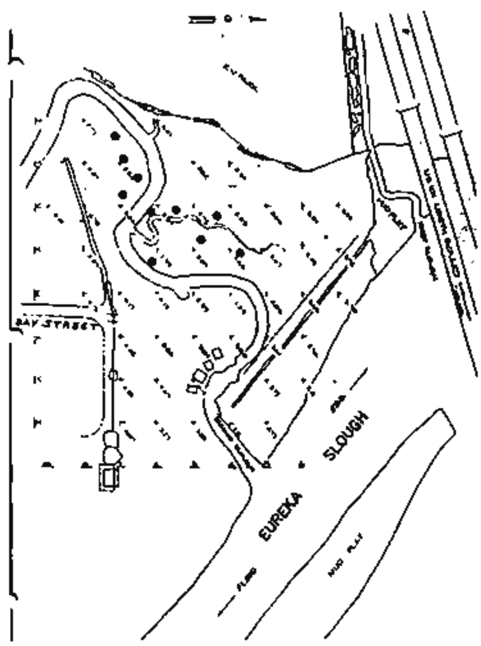


Figure 5. Salt marsh mitigation project: control study area. Filled circles are sample stations for invertebrates.

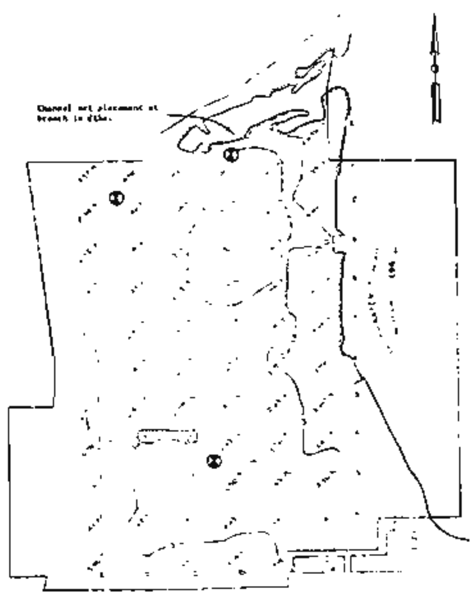


Figure 6. Restoration marsh showing elevations (height above mean high tide = 3.6 ft.), channel net placement, and drop-trap stations (⊗).

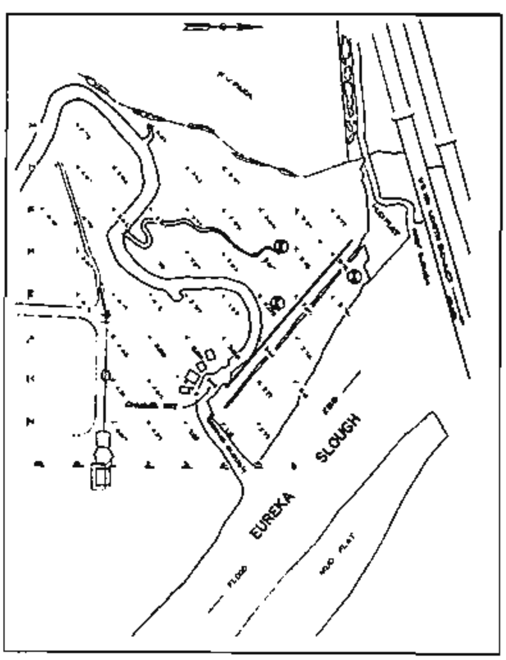


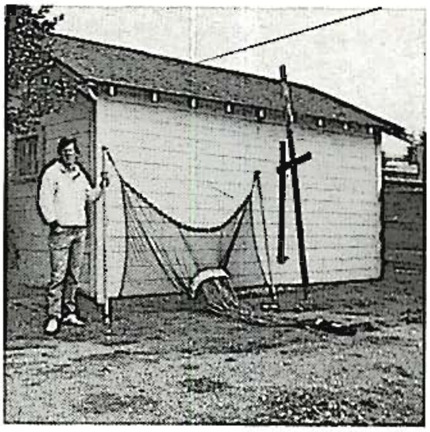
Figure 7. Salt marsh mitigation project. Control study area showing elevations (height above mean high tide = 3.6 ft.), channel-net placement, and drop-trap stations (⊗).

to estimate the volume of water filtered in order to determine density of fish captured (fish/m^3). Because both channels are dry during low tide, this net is used only during high tide. Because we have only one channel net, sampling is done at one site during the first day and is followed, if possible, by sampling at the other site the next day. The sampling schedule for a 24-hr period is divided according to tide stages in order to sample separately the flood and ebb halves of both high tides (figure 10). Four collections of approximately a 45-minute duration are taken during each high tide sampled. Fewer than the desired four collections often are made because the tide height is too low or tidal current is not sufficient to operate the flow meter or open the net. To date, the number of fish collected by this technique have been determined for each sample, and later these fish will be identified, weighed, and measured. Sampling is conducted bimonthly at each marsh as close to the same day each month as possible to prevent bias with respect to tide, light, and weather conditions. Concurrent to each sampling, salinity, water temperature, turbidity, tide stage, and water height are also noted. Component-factor analysis is being investigated as a method to assist in determining the relationship between the physiochemical parameters and biological findings. Related variables would be subsequently evaluated by analysis of variance. To date, 44 channel net samples have been taken in each marsh in the 3½ months of field effort completed. As many as 1487 larvae and 23 juvenile fish have been collected in a single 45-min sample at the restoration site.

Sampling on the marsh flats is difficult because of dense vegetation and shallow water. When deciding on a primary sampling device we wanted the equipment to have several characteristics. 1) The device needed to be able to sample quantitatively all developmental stages of fish in the marshes. 2) The equipment must not disturb the habitat and was required to be portable. We consider that the 2 m x 2 m x 4 ft. trap shown in figure 11 meets our requirements. It takes a quantitative sample by rapidly enclosing a known volume of water.

Three traps have been constructed of wood frames with transparent plastic panels to avoid attracting or frightening fish by shadow casting. The traps are set on stilts until tripped. After release the 4-m² area enclosed is seined with a specifically constructed plankton net that filters the entire trapped water column (figures 12 and 13). The restoration marsh is sampled monthly during or near the highest tide. The comparative marsh does not flood every month, so it is sampled only when the tide is sufficiently high to make operation of equipment feasible. Because tidal cycles are fixed, the light and weather conditions and the date each month that sampling occurs varies. During most tidal cycles each trap is set and released once. Therefore, three drop-trap samples are taken each month in the restoration marsh and when possible each month at the comparative marsh. Three stations in each marsh have been selected (figures 6 and 7), based primarily on distance from floodwater source. At the peak spawning time, during the spring and summer of 1982, three additional stations will be sampled in the restoration site to better typify the fish use and location in that marsh. To date, the fish collected in each trap sample have been enumerated. These fish will be identified, weighed, and measured later.

Twelve samples have been made in the restoration marsh. As many as 28 larvae and 45 juvenile fish have been collected in a single sample. Preliminary observation indicates that the dominant species residing in the marsh is the threespine stickleback, *Gasterosteus aculeatus*. To date, no fish have been collected in the comparative marsh in six drop-trap collections. The reason for this may be that the increased elevation of the comparative marsh resists flooding and decreases the transport of ichthyoplankton into this marsh. In addition, larval and juvenile sticklebacks have been observed and collected at the restoration site in high tidal pools. These pools may offer spawning habitats for the adults and rearing areas for the larvae and juveniles of stickleback and other fish. Pools only exist at the restoration site where drainage channels have not yet developed.



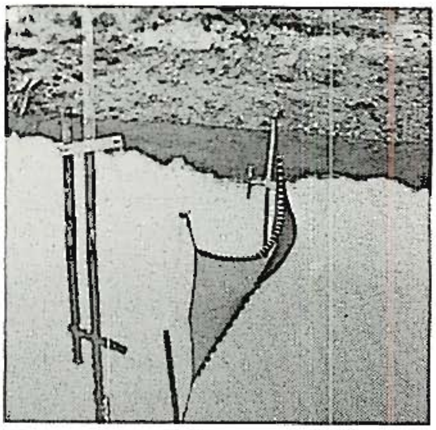


Figure 8. Channel net with attached 1/2-m plankton net and cod end. The flow meter that is staked adjacent to the net is also shown to the right.

Figure 9. Channel net and flow meter staked and fishing at breach in restoration marsh dike.

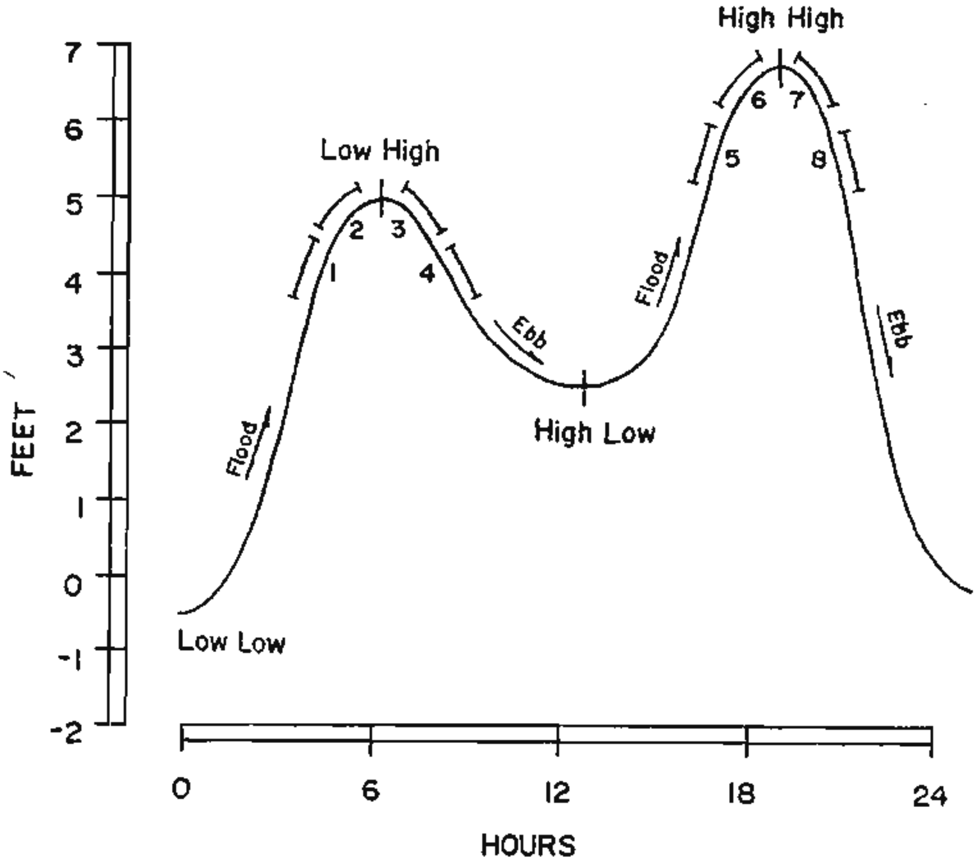


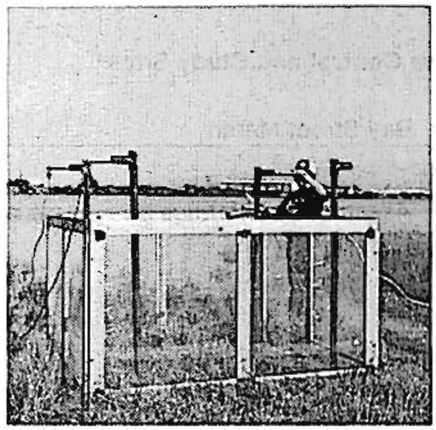
Figure 10. Typical tide curve and sampling periods used in each 24-hr study.

In August 1981, a monthly beach-seining program in the restoration marsh was begun to provide information on drop-trap and channel-net efficiency and to sample fish missed by these techniques. The same area is seined each month so that the samples can later be compared. The August and September collections were almost exclusively composed of juvenile topsmelt, *Athernops affinis*.

In September 1981, a monthly feeding study of the fish collected at the restoration site was begun. This study is being conducted by Chris Toole and is separate from this Sea Grant research project but is designed to complement and to supply valuable information relating to it. A small, fine-mesh beach seine is employed at a number of locations throughout the marsh. The stomach contents of the fish collected are analyzed to determine how and to what extent these fish are using the restoration marsh habitat. The September seining collected larvae of sticklebacks, topsmelts, and arrow gobies, *Clevelandia ios*. Preliminary work-up, by Mr. Toole, of several of the sticklebacks and topsmelt indicates that topsmelt are feeding predominately on winged insects and that sticklebacks feed on amphipods. We suspect that these food items are found in the marsh and are being taken there.

The adjacent source water for the marshes and the Woodley Island Marine Project has also been sampled for larval, juvenile, and adult fishes to determine what fish are available to use the marsh. By sampling the water near Woodley Island, a quantitative comparison between the waters adjacent to the marshes and that of the marine project can be made. This will facilitate evaluation of what fish might have used the Woodley Island marsh and in what density they occurred. By comparing fish inside and outside the marshes to what probably existed at Woodley Island, the success of the marsh restoration project can be determined and recommendation for future mitigation made.

A 16-foot otter trawl and a 1.0-m plankton net fitted with a flow meter is trawled a standard 1000 ft. The dyed plankton net is towed twice at the surface in front of each marsh and Woodley Island while the otter trawl is hauled once across the bottom for adult and juvenile fish and other organisms. We sample once a month with plankton tows on one day and otter trawls the next day. Fish-density and species-composition comparisons of plankton-net catches between areas will be determined. Otter-trawl collections will be compared using catch per unit effort. The standard physiochemical parameters and analysis methods employed by the previously discussed sampling techniques will again be used. After completion of field work in July 1982 the analyzed data will be summarized and presented along with conclusions and recommendations in a Master's thesis and an appropriate publication.



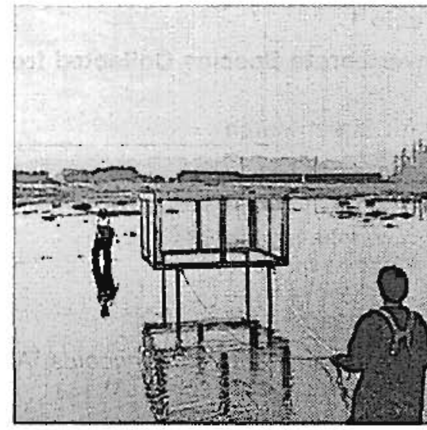


Figure 11a. 2 m x 2 m drop trap being prepared for setting.

Figure 11b. Drop trap set and ready to be released.

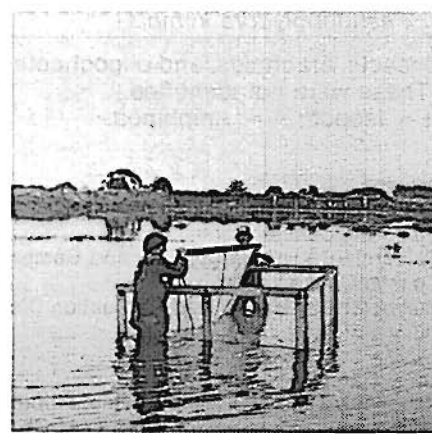


Figure 12. Plankton net used to seine inside drop trap after trap is released.

Figure 13. Plankton net being used to seine entrapped fish.

Table 1.

Invertebrate Species Collected from the Control and Study Sites[a]

Park Street Marsh	Bay Street Marsh
Gastropods	
Assiminea californica	*Assiminea californica*
Ovatella myosotis	*Ovatella myosotis*
Alderia modesta	
Crustaceans[b]	
Anisogammarus confervicolus (A)	*Orchestia traskiana* (A)
Corophium spinicorne (A)	*Armadilloniscus coronocapitalis* (I)
Orchestia traskiana (A)	*Gnorimosphaeroma oregonensis* (I)
Gnorimosphaeroma oregonensis (I)	*Littorophiloscia richardsonae* (I)
Porcellio sp. (I)	
Polychaetes	
Eteone californica	*Eteone californica*
Streblospio benedicti	
Polydora ligni	
Pseudopolydora kempi	

[a]Insects, arachnids, and oligochaetes were collected rarely at both sites. These were not identified.
[b]I = Isopod; A = Amphipod.

Cooperating Organizations
California Coastal Commission
California Department of Fish and Game
Coastal Conservancy
Humboldt Bay Harbor and Recreation Districts
Humboldt State University
Lazio's Sea Foods
Local Harbor Districts
National Marine Fisheries Service, Tiburon Laboratory
Young Adult Conservation Corp (YACC)
U.S. Fish and Wildlife Service, California Cooperative Fisheries Research Unit, and the Wildlife Research Field Station

PLANNING METHODS FOR CALIFORNIA'S COASTAL WETLAND WATERSHEDS

University of California, Berkeley
R/CZ-57
1980-82

Thomas G. Dickert

Protection of coastal resources, such as wetlands, is partially dependent on land-use activities which occur within the upstream watersheds. The purpose of this research has been to investigate those aspects of urbanization, agricultural development, and forestry practices which may affect the estuarine environment, using as case studies Elkhorn Slough (located in Monterey County) and Jacoby Creek watershed (on Humboldt Bay in northern California). The work has focused on the hydrologic processes of stream flow and sediment movement, which are perhaps the single most significant processes linking uplands to wetlands, and are processes which can be positively or negatively influenced by a land-use planning program.

The initial focus of the research has been the development of a model land-use planning system to relate the type and intensity of land use proposed 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. 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 the rates now occurring.

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

Elkhorn Slough Watershed

During 1980-81, multivariate statistical analysis of the historical time series and erosion pin transect data was completed. Results of this analysis were used to better correlate field data on erosion with mapped land characteristics. The goal of this analysis was to develop a more refined measure of erosion susceptibility in the watershed, based on characteristic landform types. The latter stage of this analysis included the use of Landsat data which was registered to the Elkhorn Slough watershed data base. It is hoped that Landsat can be used as a tool with which to monitor future changes in land disturbance levels.

The North Monterey County Local Coastal Program Land Use Plan was certified in 1981-82. The erosion control measures of the plan are heavily based on earlier results of our study. The county has adopted a planning system which sets permissible levels of development within the watershed, based on our recommended target levels for each subwatershed. Responsibility for the plan's implementation is currently being passed from the California Coastal Commission to the county. We have been actively involved in this process, meeting with local officials and recommending methods of carrying out the intent of the plan. We will also continue to provide advice and assistance to the California Coastal Commission and local agencies in applying similar planning systems within other coastal watersheds.

A computerized bibliography was initiated on the UNIX system listing references in support of the methods used in this study. The bibliography annotated references on watershed studies, nonpoint source pollution, soil erosion, statistical analysis of geographic data, and systems of geomorphological land classificiation. The bibliography currently contains 100 references, with new references being added as they are acquired.

Jacoby Creek Watershed

Testing the transferability of the approach developed at Elkhorn Slough has begun with a second case-study site on the northern California coast. The Jacoby Creek watershed tributary to Humboldt Bay was selected, as it represents conditions sufficiently similar to the Elkhorn site to provide an adequate test of the methods, but is sufficiently different in climate and physiography to provide new information on coastal watershed-wetland linkages. The watershed includes one of the few remaining salt-water wetland areas adjoining Humboldt Bay and is subject to a mix of urbanization and timber harvesting activity comparable to the urban and intensive agriculture mix at Elkhorn Slough.

Specific research tasks closely parallel those conducted in Monterey County, with particular note being made of any problems that occur in applying the techniques in the north coast field setting. Within the upland watershed, 28 erosion pin transects have been established to document the relationship between the type and intensity of land use and resultant erosion and sedimentation. The transects were established prior to the rainy season on sites representing the major soil types found in the watershed, low to high slope conditions, and land uses representing a range of forest and urban activities. Erosion and deposition were measured at the end of the rainy season and analysis comparing the erosion rates occurring on different land uses under similar soil and slope conditions is now completed. (A second set of observations for the 28 sites was made in the spring of 1982, following the end of the peak rainfall period.) An important finding is that, similar to the conclusions of the Elkhorn Slough work, vegetative cover is a greater determinant of surficial erosion than soil type, even in the highly erosive soils of the north coast.

The location and acquisition of aerial photography for the time series analysis of upland and wetland change have been completed. Aerial photographic collections of federal, state, and local agencies have been searched, and full watershed coverage has been ordered for six time periods (1941, 1948, 1958, 1970, 1974, 1978) as well as wetland coverage for 1931. Additional photographic coverage is available for use from the Humboldt County Environmental Data Collection and the Timber Assessor (1931, 1939, 1963, 1969). Also available to us is historic mapped information on Humboldt Bay (1850 to present) recently acquired from the National Archives under the coastal retreat Sea Grant project (Carver *et al.*, Humboldt State University). Interpretation of the photo sets to document the changes in land uses on the watershed and changes in wetland morphology is currently under way. The 1978 photo set was updated in 1982 by a low-altitude flight using hand-held camera and 35 mm color infrared film. Land use and vegetative cover were interpreted from the photography and transferred to stable base maps at a 1:24,000 scale; wetland units were mapped at 1:12,000. Photo interpretation classes include an extensive set of logged and revegetated units for the upland watershed and discrete deltaic units in the downstream wetland and mud flat. The minimum mapping unit ranges from 1 to 5 acres for the upland units, and ½ acre for the wetland, depending on unit type. Multivariate statistical analysis will be used to assess the correlations between periods of intensive logging and urbanization, episodic rainfall and flooding events, and changes in the delta and wetland at the mouth of the creek.

An automated geographic information system was used to prepare an erosion susceptibility map for the watershed area. The system contains data on watershed soils, geology, and physiographic characteristics. Slope categories were based on county and city development criteria and California Board of Forestry forest practices rules. Land use and erosion susceptibility units were measured using an automated digitizing system and graphical analysis package. Land use and erosion variables were aggregated by subwatershed.

Site disturbance (impervious surface and bare ground) associated with major land-use activities in the basin is being measured from large scale (1" = 600') infrared aerial photography. Projections of future disturbance will be made for the full buildout of the newly revised Jacoby Creek general plan. The site disturbance information will be coupled with the historic change analysis to produce a land-use budgeting system similar to that developed for the Elkhorn Slough watershed, and will be used to evaluate the proposed local coastal program.

The success in using the methods in this second case study support the workability of the approach for other cities and counties in developing and evaluating their local coastal plans.

Cooperating Organizations
California Coastal Commission
Humboldt County Planning Department
Monterey County (Planning and Public Works Departments)
State Lands Commission

Publications

Bean, M. 1980. A site disturbance index for California coastal watersheds: Elkhorn Slough case study. MLS thesis, Department of Landscape Architecture, University of California, Berkeley.

Dickert, T. May, 1981. Evaluating the cumulative impacts of coastal development. Invited paper at Estuarine Processes and Impacts of Alterations, Oregon Marine Science Institute, Newport, Oregon.

Dickert, T. October, 1981. Planning methods for linking the cumulative impacts of watershed development to coastal wetlands. Paper presented at the Seventh Annual Meeting of the Coastal Society, Galveston, Texas.

Dickert, T. and Tuttle, A. 1980. Linking the cumulative impacts of watershed development to coastal wetlands. Report to the California Coastal Commission and Monterey County. Institute of Urban and Regional Development, University of California, Berkeley. (Revised April, 1981).

Olshansky, R. 1982. Erosion susceptibility measures for land use planning in coastal wetland watersheds; Elkhorn Slough case study. MCP thesis, Department of City and Regional Planning, University of California, Berkeley.

SEA URCHIN DISEASES

University of California, Santa Cruz
R/CZ-58
1980-82

Ralph Hinegardner, James Pearse, Eugene Cota-Robles

Observations to date indicate that diseased sea urchins are present at low incidences in many or most healthy populations. So far, however, we have not witnessed a mass mortality or epizootic event. Nevertheless, the few naturally occurring diseased animals that we have found have enabled us to examine the basic characteristics of disease, to isolate and characterize a number of bacterial species, to perform lesion transplant experiments, and to raise a number of questions concerning host defenses or the role of the sea urchin immune system.

Since we have found sea urchins to be very resistant to disease we have investigated and found conditions which cause lesion formation and we have developed an *in vitro* cell culture technique to study the cellular nature of defense.

Disease Characteristics

Externally the most characteristic features of sea urchin disease are loss of spines and development of an easily recognized and very characteristic lesion. Histological sections of diseased portions of the base of the spine revealed massive bacterial invasion. A lesion develops in the area of spine loss, initially appearing as a large red clot owing to migration of the red granule coelomocyte cells.

A lesion is characterized by two distinct areas, an inner portion surrounded by an outer portion of very different appearance. The inner portion is a loosely aggregated, dark, friable material that is heavily infested with a variety of microorganisms including ciliates, copepods, amphipods, nematodes, and bacteria. The masses of highly motile bacteria include a large variety of forms. Superficially they can be long, short, fat, thin rods, spherical, and spiral (figures 1, 2, and 3).

The outer portion that surrounds the center is swollen, light in color, and appears to be enclosed within a membrane. Phase microscopy of this material indicates it is very cellular with very prominant vibratile and red granule cells. Both of these cell types are found in coelomic fluid. This portion is not infested with microorganisms. This is surprising and future research will be directed at understanding why.

Other characteristics associated with diseased sea urchins include edema, weak tube feet adherence, peeling epithelium, and impaired ability of the urchin to right itself.

Internal changes observed in diseased sea urchins include a massive increase of clumping in the circulation, phagocytosis, and excretion by constricting spheroids from the gill structures, tube feet, and other external surfaces. There are also changes in the coelomic cells.

Bacterial Isolation

A number of bacteria were isolated from both coelomic fluid and lesions of diseased sea urchins. Thirty-two biochemical tests were utilized to characterize the bacteria. In addition, antibiotic sensitivity, NaCl requirement, optimal temperature for growth, and sensitivity to the vibriostat compound 0/129 were determined. The majority of the isolates are Gram-negative motile rods. Only two isolates can grow at 37°C and all except one have a NaCl requirement that matches sea water. The results of these tests, summarized in table 1, identify the isolates as *Vibrio anguillarum* (1, 10, 11), *Aeromonas salmonicida* (16, 25), several species of flavobacteria (2, 3, 4, 13, 14, 26, 28, 31), and a pseudomonad (29).

Agarose gel electrophoresis, used in screening for the presence of extrachromosomal plasmid DNA in the above isolates, determined that isolate numbers 1, 2, 3, 10, 11, 16, 25, and 26 contain plasmids. Isolates 28, 29, and 31 do not contain plasmids and isolates 4, 13, and 14 have yielded inconclusive results. Isolates 3, 10, and 11 (10 and 11 are *V. anguillarum*) may contain two different molecular weight plasmids. The significance of the presence of plasmid DNA is being studied to further elucidate the role it may or may not play in enabling its host bacteria to cause disease. (J. H. Crosa, University of Oregon, recently determined that the highly virulent strain of the marine fish pathogen, *Vibrio anguillarum*, harbors a plasmid.)

Infectivity experiments

Various types of infectivity experiments included the transplantation of lesion material, application of bacteria directly onto the sea urchin epithelium, and suspension of bacteria in water containing the sea urchin. Parameters such as stress (starvation or mechanical abrasion) and repeated exposures over time were incorporated into the experiments.

Experiments involving transplantation of lesion material determined that the characteristic lesions would form on the healthy animal only if the external epithelium was mechanically abraded first. Close contact of a wounded sea urchin (via mechanical abrasion) with others having lesions led to formation of small lesions on the wounded area which healed quickly. Transfer of lesion material onto nonwounded (healthy) animals increased phagocytosis of the aforementioned amebocytes but no lesions developed. Close contact between healthy sea urchins and those with lesions did not cause lesion formation.

The results of experiments involving application of bacteria directly onto the epithelium indicated a similar requirement for prior mechanical abrasion before a lesion would develop. The interesting result, however, was that lesions would develop only when isolate numbers 1, 10, 11, 16, or 25 (all of which contain plasmids) were applied to the wounded area. Even when applied to the wounded surface the other isolates did not cause lesion development.

Animals that had been starved in addition to mechanically abraded before exposure to the above bacterial isolates died within 2 days with a much reduced characteristic lesion formation occurring.

Experiments involving suspension of bacteria in water containing healthy sea urchins determined that the sea urchin is very resistant to this type of exposure. Neither of the bacterial species mentioned above (*V. anguillarum* and *A. salmonicida*) were found to cause lesion formation when suspended in the water. However, the addition of either of these bacterial species to the water containing the sea urchin caused visible distress to the animal such as tube feet and spines drooping and remaining motionless for the length of exposure to the bacteria. Repeated exposures (5 exposures, 1 each day, 5 days duration) gave similar results.

In vitro cell culture

In the process of developing a culture medium to maintain sea urchin coelomic cells *in vitro* the coelomic fluid from healthy and stressed or diseased animals was analyzed for ionic and protein content. Also, the appearance and abundance of the four coelomic cell types and the viscous nature of the coelomic fluid was compared. The ionic composition of the sea urchin coelomic fluid is very similar to that of seawater with the exception of phosphate. The phosphate content in coelomic fluid is 31 mg/liter compared to 0.09 mg/liter in seawater. A Lowry protein assay determined that the healthy sea urchin coelomic fluid contains 6 mg/ml protein compared to 27 mg/ml protein content in coelomic fluid of the stressed or diseased animal. Comparison of the appearance of the coelomic fluid and the abundance of the coelomic cell types revealed the following differences: healthy animals had relatively clear fluid with abundant cells of all four types, whereas stressed or diseased animals had a dark, debris-filled, turbid and viscous fluid, and few red granule, clear granule, or vibratile cells. The fourth cell type, a phagocytic cell (the amebocyte), was observed to contain large quantities of engulfed material in the stressed animal. Based on the ionic content of sea urchin coelomic fluid the following culture medium was prepared: NaCl, 25.4 g/liter; KCl, 0.9 g/liter; $CaCl_2 \cdot 2\,H_2O$, 1.6 g/liter; $MgCl_2 \cdot 6\,H_2O$, 9.9 g/liter; $Na_2HPO_4 \cdot 12\,H_2O$, 0.11 g/liter; Hepes 25mM, 5.95 g/liter; 1 N NaOH, 100 ml; distilled water to volume; pH 7.4.

The initial objectives of the cell culture technique were to observe and maintain the cells *in vitro*. Additionally, response of the cells to an inoculum of bacteria has been observed. Coelomic cells from healthy animals formed a well-spread monolayer. The cells exhibited great mobility and moved toward and away from each other by extending and retracting pseudopods. They actively phagocytized bacteria into phagosomes or vacuoles which were transported to and accumulated around the nuclei. Over time, degradation of the bacteria in vacuoles was observed. After 24 hours in the culture medium healthy cells continued to phagocytize bacteria.

Coelomic cells from the stressed animal (starved or diseased) did not exhibit all the aforementioned characteristics in the *in vitro* culture. They spread but appeared to have more debris and other cells adhering to their surface. Upon withdrawal from the coelom of the sea urchin, the cells contained numerous large vacuoles surrounding the nucleus. Most of the vacuoles appeared empty with some containing red granules or other debris. The cells were not observed to actively phagocytize an inoculum of bacteria. Over time, the cells from stressed animals disintegrated in culture.

The above results have led to an understanding of the basic disease characteristics and the course of infection in the sea urchin. Although none of the bacterial isolates were able by themselves to induce disease in normal, healthy animals, several species were found to be highly infectious under conditions of stress such as starvation or mechanical abrading. The role that extrachromosomal plasmid DNA plays in the ability of the bacterial host to cause disease is yet to be determined. Also still to be determined is the specific nature of cellular defense of the sea urchin coelomic cells. The *in vitro* culture technique has raised many questions and studies on the activities of the sea urchin coelomic cells are pertinent to understanding their role in host defense.

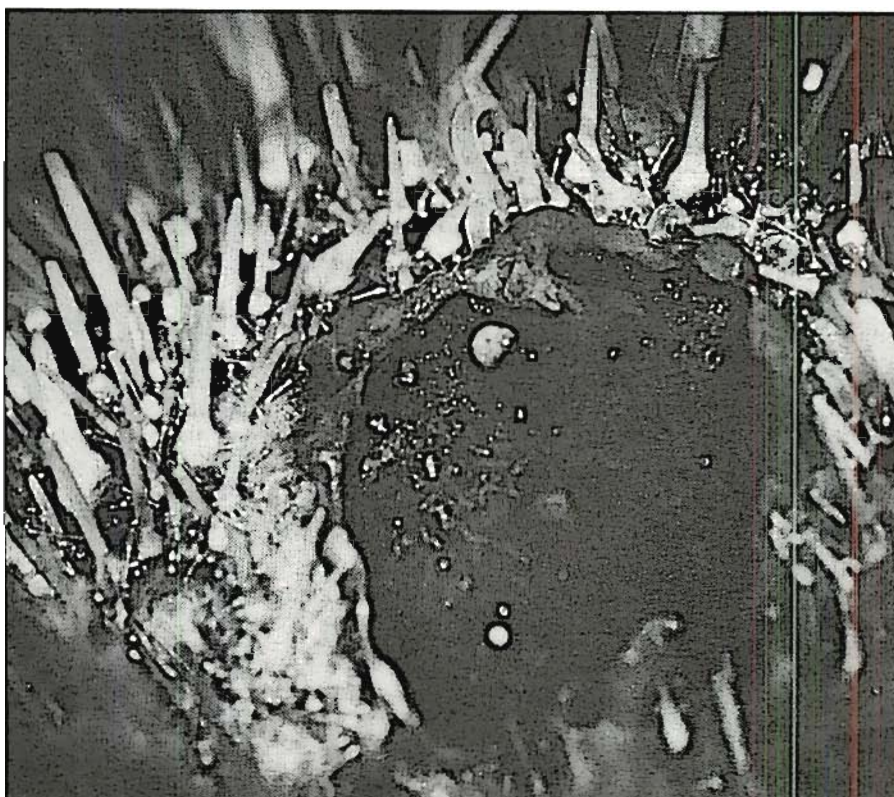
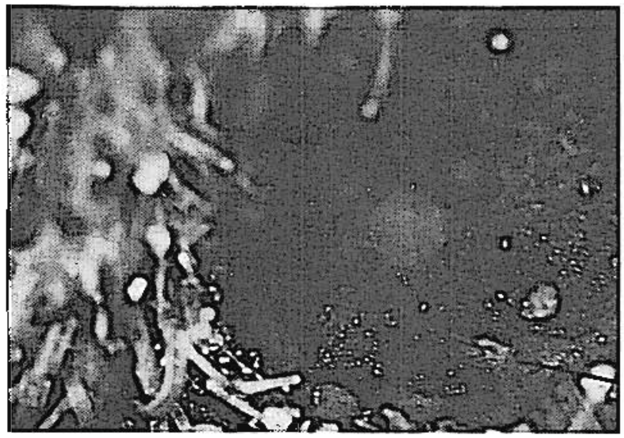


Figure 1. Low magnification (2x) of a lesion on a diseased sea urchin (*Strongylocentrotus purpuratus*).



S

Figure 2. Characteristic appearance of a lesion on a diseased sea urchin showing the dark, friable material in the center surrounded by a swollen, shiny, membrane-enclosed outer part (S). 3x.

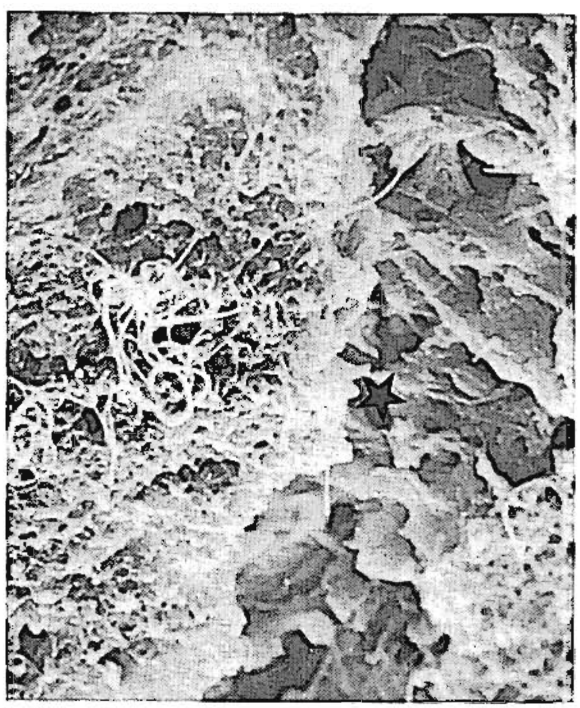


Figure 3. SEM of a section of test from a diseased sea urchin, *Arbacia punctulata*, showing the test flaking" away and filamentous bacteria. 770x.

Table 1

Characteristics of Bacteria Isolated from Diseased *S. purpuratus*[a]

Isolate Number	1	2	3	4	10	11	13	14	16	25	26	28	29	31
Gram stain	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Motility	+	+	+	+	+	-	-	-	+	+	+	-	+	+
Plasmid DNA	+	+	+	UD	+	+	UD	UD	+	+	+	-	-	-
Temperature Sensitivity														
37°C	-	-	-	-	∓	-	-	-	-	-	-	+	+	-
22°C	+	+	+	+	+	+	-	+	+	+	-	+	+	-
12°C	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Carbon source														
Saccharose	-	-	±	-	+	+	+	-	-	-	-	+	-	-
Dextrose	+	+	-	-	+	+	-	-	-	+	-	-	-	-
Glucose	+	-	±	-	+	+	∓	-	+	+	-	-	+	-
Sucrose	-	-	-	-	+	+	-	-	-	-	-	-	+	-
Mannitol	+	-	±	-	+	+	-	-	+	+	-	-	+	-
Maltose	+	-	-	-	+	+	-	-	+	+	-	-	+	-
Lactose	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Inositol	-	-	±	-	-	-	-	-	-	-	-	-	±	-
Sorbitol	+	-	±	-	∓	∓	-	-	∓	∓	-	-	-	-
Rhamnose	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melibiose	+	-	-	-	∓	-	-	-	∓	∓	-	-	-	-
Amygdalin	+	-	+	-	+	+	-	-	-	+	-	+	-	-
Arabinose	-	-	∓	-	-	∓	+	-	-	-	-	-	-	-
Antibiotic sensitivity														
Penicillin	-	-	-	+	∓	∓	+	∓	+	-	+	+	-	-
Chloramphenicol	+	+	+	+	+	+	+	+	+	+	+	+	-	+
Naladixic Acid	-	+	+	+	-	-	+	+	+	-	+	-	-	+
Tetracycline	+	-	-	-	-	+	-	+	+	-	-	-	-	-
Ampicillin	-	+	+	+	+	+	+	+	+	-	-	+	-	+
Erythromycin	-	+	-	+	-	∓	+	+	∓	-	-	+	-	-
Polymyxin B	+	+	+	-	+	+	+	+	+	+	+	+	-	+
Streptomycin	-	-	+	-	+	-	-	-	+	-	-	-	-	-
Biochemical Tests														
Gelatin liquefaction	+	+	±	+	+	+	-	+	+	+	+	-	±	-
H_2S production	-	-	-	+	-	-	-	-	-	-	+	-	-	-
Nitrate reduction	-	-	-	-	+	+	-	-	+	+	-	-	-	-
Arginine dihydrolase	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lysine decarboxylase	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ornithine decarboxylase	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vogues-Proskauer	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Indole	-	-	-	-	+	+	-	-	+	+	-	-	-	-
Urease	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Citrate	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxidase	+	+	+	+	+	+	+	+	+	+	+	-	-	+
Catalase	+	+	+	+	+	+	-	+	+	+	±	+	+	-
ONPG	+	+	-	+	+	+	-	-	+	+	-	+	+	-
Tryptophane deaminase	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NaCl Requirement (2.6%)	+	+	+	+	+	+	+	+	+	+	+	+	-	+
Starch	+	+	-	+	+	+	+	+	+	+	+	+	+	+
Chitinase	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lipase	+	+	+	+	+	+	±	+	+	+	+	-	-	+
Protease	+	+	-	+	+	+	-	+	+	+	-	+	∓	-
TCBS	+	-	-	-	+	+	-	-	+	+	+	-	-	-
Vibriostat O/129	+	-	-	-	+	+	-	-	-	-	-	-	-	-
Agar digestion	-	+	-	-	-	-	-	-	+	-	+	-	-	-
Bioluminescence	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[a]+, Positive, present or sensitive; -, negative, not present or resistant; ±, both positive and negative present, the predominant reaction above; UD, undetermined.

WATER CURRENTS AND MIXING RATES IN KELP BEDS

University of California, San Diego
R/CZ-59
1980-82

George Jackson and Clinton D. Winant

Our project was designed to measure the magnitude of currents in a kelp bed, to determine how different these currents are from those in a kelp-free area, and to explore how current regime affects transport of substances around a kelp bed. We proposed to deploy current meters in the Point Loma kelp bed and a site to the north during two different seasons, to analyze this data statistically, and to develop models of the processes involved.

We have made five current meter deployments to date, under winter and summer conditions for periods ranging from about a week to almost a month. Our analysis of the data thus far has shown that currents within the kelp bed are significantly slower than those outside, about one-third as fast. The dampening of water motions within the bed is not uniform for all frequencies but is much less pronounced for the semidiurnal tidal motion that occurs in the longshore direction. Currents are slow enough for water to have residence times in the bed as long as a week.

Measurements of the vertical current structure show that kelp bed currents have much less vertical shear. This suggests that various baroclinic motions, such as internal waves, are more heavily damped than barotropic motions. The semidiurnal motion that is more pronounced in the kelp bed is one such barotropic motion.

We have compared the drag expected for a kelp bed with that observed for a sandy bottom. The differences in the drag for the two coastal situations are compatible with differences in current velocities at the two sites. These differences in drag and current velocities imply a transition region at the upstream edge of the kelp bed on the order of 100 m.

We have twice deployed arrays of meters at various locations within the kelp bed to study spatial variability of kelp bed currents and temperature fluctuations.

Because of instrumental failures during the first deployment, our data records are incomplete and our analyses only preliminary. We have just completed the second deployment but have not yet begun to study these data.

To discuss spatial variation within the kelp bed during a summer deployment we will use the limited 1981 record. Current-meter moorings ranged over a longshore distance of 2.4 km and had cross-shore position relative to the seaward edge ranging from 140 m outside to 550 m inside. Current meters were near the surface (4 m below MLLW) in about 14 m water.

Temperature records show a very high correlation among temperatures at the different surface waters. Fluctuations are strong in tidal frequencies and can change as much as 4°C in a few hours. Spectral analysis shows dampening of high frequency motions but not those of low frequency. Most of the variance is associated with low frequencies.

Longshore currents decrease dramatically across the kelp bed. Outside the bed, at station O, mean and standard deviation of the longshore current were 2.1 and 8.6 cm/second, respectively. At the innermost station, station C, mean and standard deviation were -0.3 and 0.9 cm/second, respectively. Stations closer to the seaward edge had intermediate means and standard deviations.

Cross-shore currents also decrease dramatically across the bed. At station O, mean and standard deviation were -0.1 and 3.8 cm/second, respectively. At station C, mean and standard deviation were 0.3 and 0.8 cm/second, respectively. Again, stations nearer the seaward edge had values higher than those closer to the outside edge.

Preliminary spectral data show that cross-shore currents in the kelp bed are coherent with semidiurnal tides. This is somewhat surprising because currents in a kelp-free area at Del Mar (some 20 km north) were not, presumably because pure tidal currents were relatively unimportant. The situation seems to differ in the weak current regime of the kelp bed.

During the winter important flows in the kelp bed are longshore. These are fairly uniform vertically. During the summer, when a strong thermocline forms at middepths in the kelp bed, longshore currents are very weak. Cross-shore movement — whether it be onshore at the surface, offshore below the surface, or some other mode — becomes more important for moving water in and out of the kelp bed.

Our results show that the kelp bed influences its physical environment just as a terrestrial forest does. We are working to decipher the mechanisms so that we can describe the exchange of materials with the surrounding area and within the bed. Experience with terrestrials shows that this will be vital to understanding the kelp ecosystem.

Publications

Jackson, G. A. 1982. Effects of a kelp bed on coastal currents. Talk presented at Ocean Sciences, AGU/ASLO Joint Meeting, San Antonio, Texas, February, 1982.

Jackson, G. A. and Winant, C. D. 1982. Effect of a kelp forest on coastal currents. (Submitted to Continental Shelf Research).

LIQUEFACTION POTENTIAL OF COASTAL FILLS

San Diego State University
R/CZ-61
1980-81

Iraj Noorany

The purpose of this research was to study the soil conditions at Harbor Island in San Diego Bay and to evaluate its liquefaction potential. Harbor Island is typical of many coastal fills in California.

The construction history of Harbor Island was studied and, based on the available records of soil borings, soil profiles along different cross sections were developed. The regional seismology of southern California was studied to identify the significant earthquakes that would affect the site. A liquefaction analysis was performed utilizing a method developed at the University of California, Berkeley based on observation of the performance of sand and silty sand deposits in previous earthquakes (Seed and Idriss, 1981). A study of mitigating measures for reducing or eliminating the liquefaction potential is currently being performed.

Soil Conditions in Harbor Island

Harbor Island was constructed as a result of a bay dredging project by the U.S. Army Corps of Engineers in 1961. Approximately 3.4 million cubic yards of material were dredged from the bay and deposited to build the 70-acre island. Immediately after completion of the filling operation, the perimeter of the island was riprapped to protect it from erosion.

In 1967, the isthmus portion of the island was widened by approximately 200 feet. The material for this addition was obtained from dredging the marina area north of the island and fill that was trucked over from the vicinity of the airport.

The average ground surface elevation of Harbor Island is +14 MLLW. The site is underlain by approximately 23 feet of hydraulic fill, underlain by about 10 feet of Holocene bay deposits, underlain by very dense Pleistocene terrace deposits. The average ground water elevation is at +4 MLLW and fluctuates as the tide fluctuates from approximately -2 to +6 MLLW.

The hydraulic fill consists of clean to silty sands that classify as SP, SP-SM, and SM by the unified soil classification system. The bay deposits consist of clean to silty sands and classify as SP, SP-SM, and SM soils.

Seismic Exposure of Harbor Island

Harbor Island is located within a wide zone of faults bounded on the east by the San Andreas fault and on the west by the San Clemente fault. Within this wide zone, six other fault systems have been identified to characterize the seismic exposure of the Harbor Island site. These are listed in table 1 and their locations are shown in figure 1.

To date, no direct evidence has been established of Holocene displacement in the San Diego area. However, most of the Quaternary faults in the coastal zone are generally considered by the California Division of Mines and Geology to be "potentially active." Because of lack of sufficient historic or recorded earthquake data in this study, the seismic activity of most of these faults has been estimated primarily based on the available geologic evidence.

Figure 2 shows that the degree of seismic activity of each fault zone is characterized by a magnitude recurrence curve which shows the expected cumulative annual events of each fault. This figure was prepared based on the available instrumental records of seismic events, geologic considerations, estimates of average fault slip rates (table 1), and other seismological considerations (Woodward-Clyde Consultants, 1981). The magnitude recurrence curves in figure 2 were used together with ground attenuation relationships developed by Schnaubel and Seed (1973) and Idriss (1978) in order to relate earthquake magnitude, distance of site to fault, maximum ground acceleration, and recurrence interval. From this analysis, a set of curves was developed showing probabilities of exceedance of peak ground accelerations at Harbor Island caused by each fault and the combined probability caused by all relevant faults for several return periods. An example for a return period of 50 years is shown in figure 3.

It must be emphasized that the results shown in figure 3 are based on relatively limited earthquake and geologic data and may be modified as new or more reliable data regarding fault activities become available.

Liquefaction Analysis

The liquefaction analysis was made based on a semi-empirical method developed at UC Berkeley. This method is based on field observations of the performance of sand and silty sand deposits in previous earthquakes and requires the use of standard penetration resistance blow counts of the soil deposit.

In order to use the above method, the measured penetration resistance blow counts (N) at Harbor Island were corrected for the effective overburden pressure, the type of sampler, the silt content (Seed *et al.*, 1981) and the length of drill rods (Schmertmann, 1977). The resultant blow count is referred to as the modified standard penetration resistance, N_1. After a statistical treatment of the N_1 values, cumulative distribution curves were plotted to obtain the median and range of values for each type of soil deposit. These characteristic blow counts will be used to evaluate the liquefaction potential of each layer.

The most recently developed general liquefaction analysis curves (Seed *et al.*, 1981) relating cyclic stress ration causing liquefaction and modified penetration resistance, N_1, were utilized to prepare two site-specific liquefaction analysis charts for Harbor Island (figures 4 and 5). These charts can be used along with the representative adjusted blow counts, N_1, to evaluate the peak acceleration ratios, a_{max}/g, that will cause liquefaction if exceeded. This part of the analysis and an evaluation of the probability of such an event is currently under way.

Work is also in progress to evaluate the extent of potential damage upon liquefaction and mitigating measures that would help reduce the potential for liquefaction.

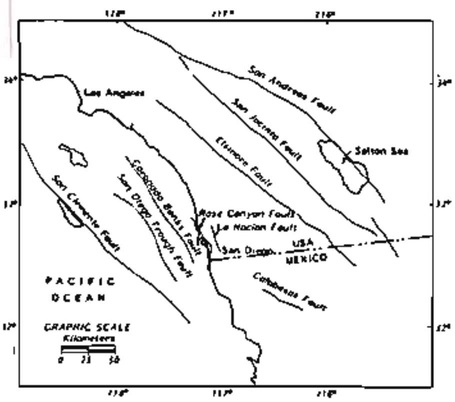


Figure 1. Faults affecting seismicity of Harbor Island.

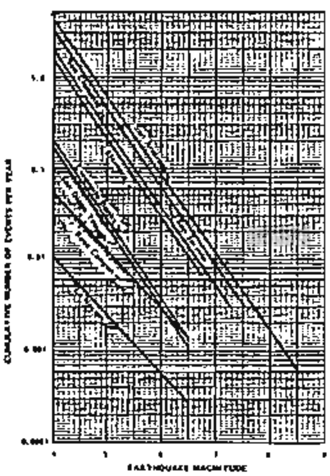


Figure 2. Magnitude-recurrence curves.

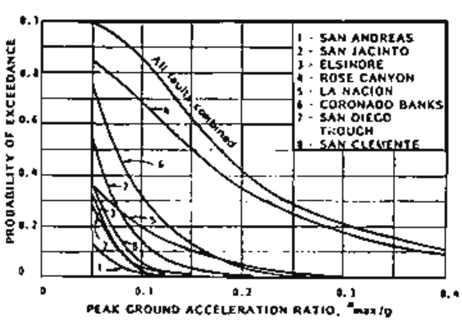


Figure 3. Probability of exceedance of peak ground acceleration in 50 years at Harbor Island.

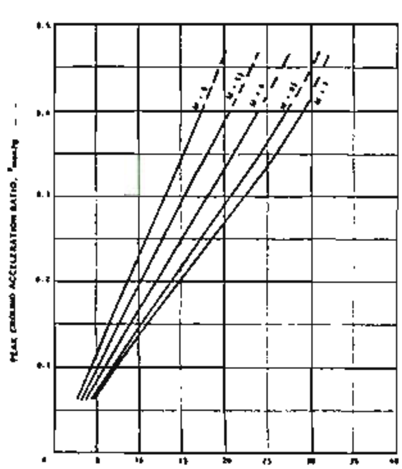


Figure 4. Chart for evaluation of liquefaction potential of hydraulic fill in Harbor Island.

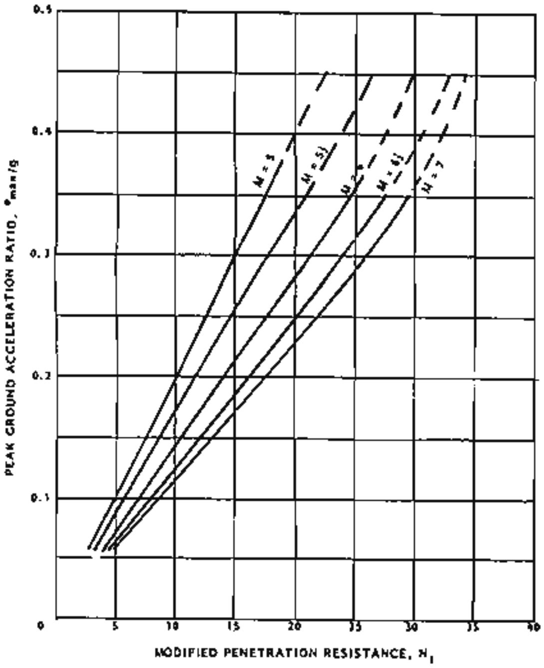


Figure 5. Chart for evaluation of liquefaction potential of bay deposits in Harbor Island.

Table 1

Fault Characteristics

Fault Name	Type	Length (km)	Slip Rate (mm/yr)	Distance (km)	Maximum Magnitude
Rose Canyon	Oblique	64	0.2	2	6-1/2
La Nacion	Normal	25	0.1	10	6-1/2
Coronado Banks	Right-Lateral	122	0.2	20	6-1/2
San Diego Trough	Right-Lateral	106	0.2	30	6-1/2
San Clemente	Right-Lateral	356	2	77	7-1/4
San Andreas	Right-Lateral	416	25	146	8-1/2
San Jacinto	Right-Lateral	260	7.1	102	7-1/2
Elsinore	Right-Lateral	230	1.2	69	6-3/4

(From: Woodward-Clyde Consultants, 1981)

Cooperating Organizations

City of San Diego
Unified Port District
U.S. Navy
Woodward-Clyde Consultants

References

IDRISS, I. M. 1978. Characteristics of earthquake ground motions — state-of-the-art paper. In *Proc. of specialty conference on earthquake engineering and soil dynamics. III.* Pasadena, California, June 1978.

SCHMERTMANN, J. H. 1977. Use the SPT to measure dynamic properties? Yes, but... In *Proc. American Society for Testing and Materials.* Symposium on Dynamic Field and Laboratory Testing of Soil and Rock, Denver, Colorado, 1977.

SCHNAUBEL, P. B. AND SEED, H. B. 1973. Accelerations in rock for earthquakes in the western United States. Bulletin of Seismological Society of America 63(2):501-516.

SEED, H. B. AND IDRESS, I. M. In press. 1981. In *Evaluation of liquefaction potential of sand deposits based on observations of performance in previous earthquakes.* University of California, Berkeley.

WOODWARD-CLYDE CONSULTANTS. 1981. Seismic exposure of Harbor Island. San Diego State University Sea Grant Project, 1981.

AQUACULTURE

DEVELOPMENT OF THE SCIENCE AND TECHNOLOGY OF CRUSTACEAN AQUACULTURE

University of California, Davis
R/A-28
1980-81

Wallis H. Clark, Douglas E. Conklin, and Cadet Hand

During the years 1978 through 1981 we pursued multidisciplinary research on significant problem areas in crustacean aquaculture. These problems are categorized into the subproject areas of broodstock development, endocrinology and larval biology, nutrition, pathology and engineering; some major accomplishments of each subproject are described here.

Broodstock Development

Control of the reproductive cycles is necessary to ensure seed supply and allow genetic improvement of cultured crustaceans. Our research has focused on gamete biology and on environmental and physiological controls of reproductive cycles.

We have characterized the gametes and examined fertilization in five species of shrimp — *Sicyonia ingentis, Penaeus aztecus, Macrobrachium rosenbergii, Palaemon macrodactylus*, and *Pandalus danae* — chosen as representative of commercially important penaeid and caridean natantians.

Preliminary studies of *S. ingentis* indicate that eyestalk extracts may mediate the breakdown of the germinal vesicle and release of the eggs from their surrounding matrix of follicle cells. Following spawning in *S. ingentis* and *P. aztecus*, the next critical event is the cortical reaction (jelly release) of the eggs which has been morphologically and biochemically characterized.

We have also made significant progress in understanding the fertilization events in *S. ingentis* (i.e., binding, activation, and fusion of gametes; figure 1). The acrosome of the sperm has been characterized, and the acrosomal reaction has been successfully induced *in vitro* with the ionophore A23187 and an egg envelope fraction. Other studies have shown that the caridean shrimp, *M. rosenbergii* and *P. macrodactylus*, possess identical gametes. The sperm of these animals have been structurally and physiologically characterized, and the events of fertilization in *M. rosenbergii* have been thoroughly documented. In preliminary work, we have morphologically characterized the gametes of *P. danae* and examined the early events of sperm-egg association.

A series of experiments and observations on lobsters (*Homarus*) has provided the first definitive evidence for a decapod crustacean that secondary vitellogenesis and extrusion are controlled by photoperiod and molting. Four months of short days (8 hr L:16 hr D) appear to ready the ovary for final egg development; under short days secondary vitellogenesis is inhibited and molting has no effect on the timing of eventual egg extrusion. Following long day onset (16 hr L: 8 hr D), secondary vitellogenesis commences and extrusion occurs in about 125 days. Molting within the first 45 days following long day onset has no effect on the timing of egg extrusion, but molting after this time delays extrusion (figure 2) with the molt-extrusion interval averaging about 90-100 days.

Although details of the lobster's reproductive and molting cycles require further study, photoperiod control appears to offer a relatively inexpensive means of controlling seed supply in lobster culture. For example, females held under short days until late August were exposed to long days in late summer and thereby induced to spawn in midwinter. Hatching larvae were thus available in early spring when they would have otherwise been difficult to obtain from wild-caught, berried females.

Endocrinology and Larval Biology

During the past 3 years of the grant period, we have established a functional endocrinology laboratory that is equipped to conduct experiments involving immunological techniques, chromatography (thin-layer, column, and high-performance liquid), radiolabeled compounds, and gel electrophoresis. Specifically, we have examined alterations in the ecdysone titer of juvenile lobsters by means of a sensitive radioimmunoassay (RIA). Levels of this molting hormone are low during postmolt and intermolt but increase dramatically at premolt (figure 3). In addition, we have determined that molt acceleration in eyestalk ablated lobsters is correlated not with an overall elevation of molting hormone concentrations but with a reduction in the length of time that ecdysone titers are low.

In the larval states, we have determined for the first time in any crustacean species that 20-hydroxyecdysone is the only detectable molting hormone and that it changes in concentration during the larval molts. Thus this hormone appears to coordinate not only juvenile and adult molting, but larval development as well.

Recently we have demonstrated that fifth stage lobsters are a suitable bioassay for the detection of molt-inhibiting hormone (MIH) activity in extracts from adult lobster sinus glands. We are currently using this bioassay system to purify and chemically characterize the MIH molecule and to determine its mode of action in preventing molting.

Nutrition

After 2.5 years, our growth experiments involving juvenile lobsters grown exclusively on artificial diets continue successfully (figure 4). Present growth rates indicate that some lobsters will attain market size (500 grams) within 2.6 years. In the near future we will be able to determine whether our diets will be adequate for normal sexual maturation and fertility.

Studies using radiolabeled cholesterol have substantiated our hypothesis regarding the relationship between the absence of lecithin in a purified diet and mortality. Absence of lecithin is associated with significantly lower transport rates of cholesterol from the hepatopancreas to the hemolymph (figure 5). An associated study of serum cholesterol titers throughout the lobster molt cycle has shown that vast quantities of cholesterol are mobilized from the hepatopancreas to the hemolymph just prior to molting but before the premolt increase in ecdysteroid titers discovered by Dr. Chang.

We have attempted to substitute the cholesterol in our diet with phytosterols (plant source sterols). Cholesterol is a required nutrient but a comparatively expensive ingredient; substitution with plant sterols would allow a significant reduction in feed costs. With phytosterols present in the diet survival is good but growth rates are significantly lower than the control diet containing cholesterol.

Through replicate experiments we have confirmed that the protein content of the artificial diets can be reduced to 30-35% (dry weight) without any significant reductions in growth rates. This success is partially dependent upon the quality of protein in the diet. Diets containing casein with shrimp meal or freeze-dried euphausiids provide a good source of protein. We have begun to investigate the optimal levels of various fats and carbohydrates associated with the low protein diet. This approach is designed to ensure that the available protein is used exclusively for growth rather than respiratory activities.

Pathology and Water Quality

The Microbiology/Pathology lab continues to provide free disease diagnostic services for California aquaculturists. In addition it provides assistance in all disease-related problems for other research groups at BML. Disease organisms are isolated and identified, and corrective measures are recommended.

A survey of reported bacterial pathogens of marine fish and shellfish was completed and a diagnostic flow chart developed to help the aquaculturist acquire economical, on-site procedures for isolating and identifying bacterial pathogens. This facilitates a more rapid application of appropriate treatments.

Our Water Quality Laboratory maintained its state certification and assisted other subprojects with water and chemical analyses such as gas chromatographic identification of fatty acids for nutrition.

Engineering

Several design iterations of a new concept for handling individual culture cells in high-density, high-water-quality systems have been considered. The basic concept involves long racetrack trays in which cell modules circulate by means of friction drive. The trays are stacked directly on top of one another in staggered fashion to allow access to alternate trays at opposite ends; the stack is self-supporting. Water powered actuators drive an underwater cable that in turn causes floating cell modules to circulate.

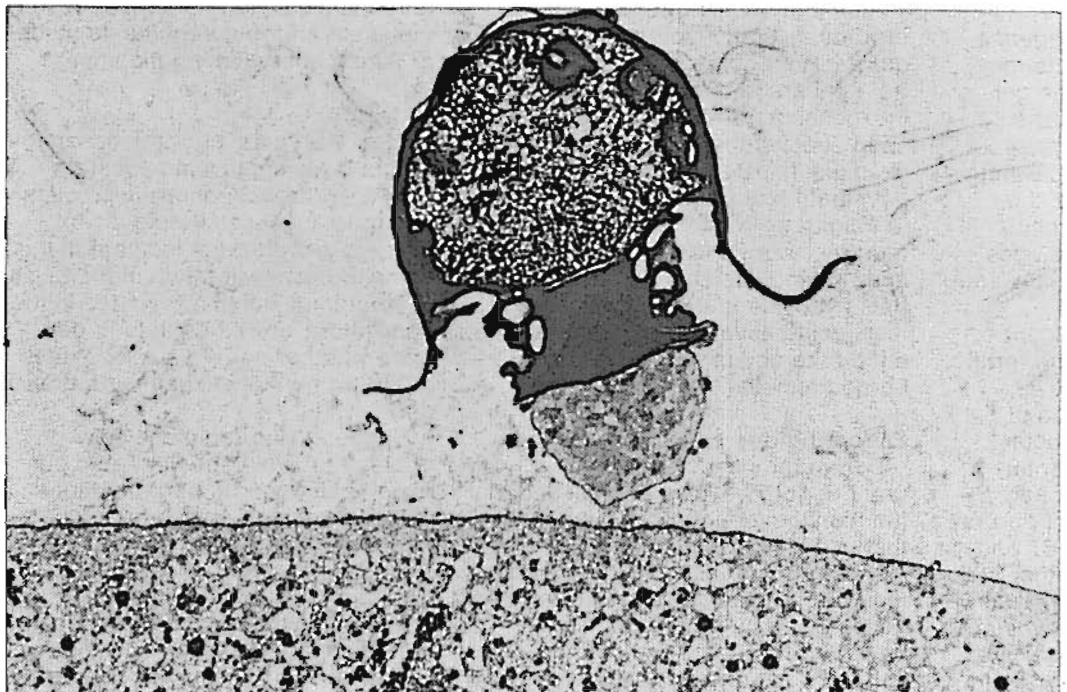


Figure 1. Electron micrograph illustrating sperm-egg interaction in the ridgeback prawn.

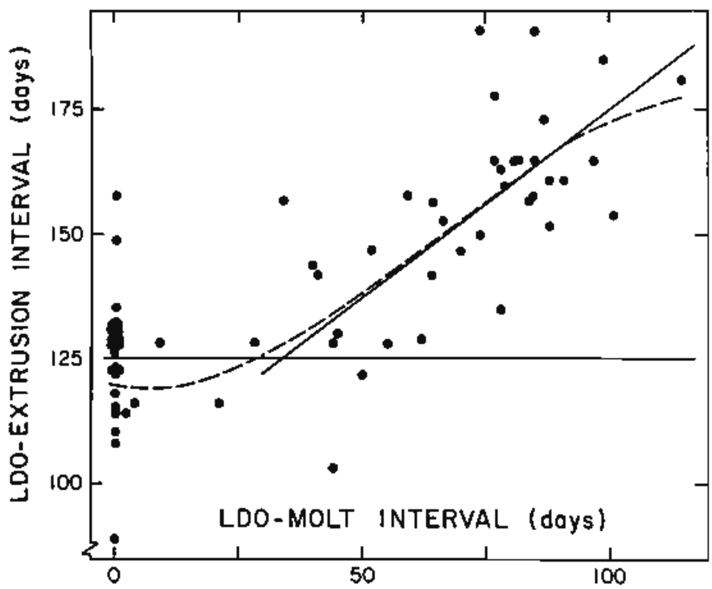


Figure 2. Relationships between experimental long day onset (LDO; 16 hrs L: 8 hrs D) extrusion and molting in female lobsters (*Homarus americanus*). Group of points at far left shows an average LDO-extrusion interval of 125 days when no molt intervenes. Solid and dotted lines are linear and polynomial least squares fits respectively to data beyond an LDO-molt interval of 45 days.

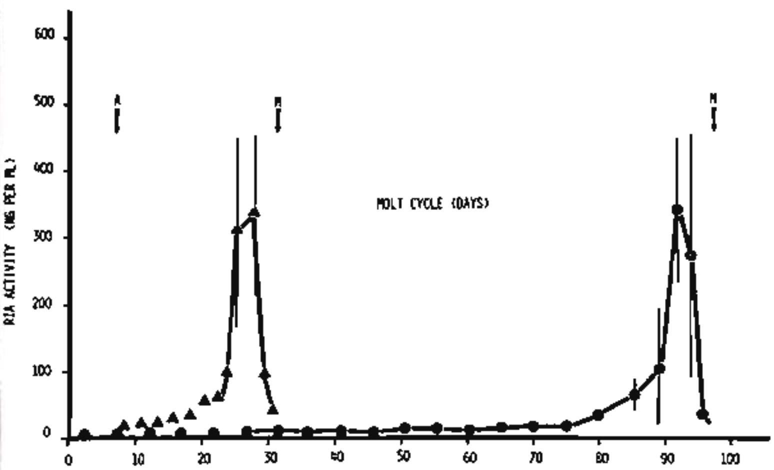


Figure 3. Hemolymph molting hormone concentration (RIA activity) during the course of the molt cycle of *Homarus americanus*. Animals were either eyestalk ablated (triangles) 7 days postmolt or left intact (circles) and kept at 20°C. Vertical lines represent standard deviations. The arrows indicate the time of ablation (A) or molt (M).

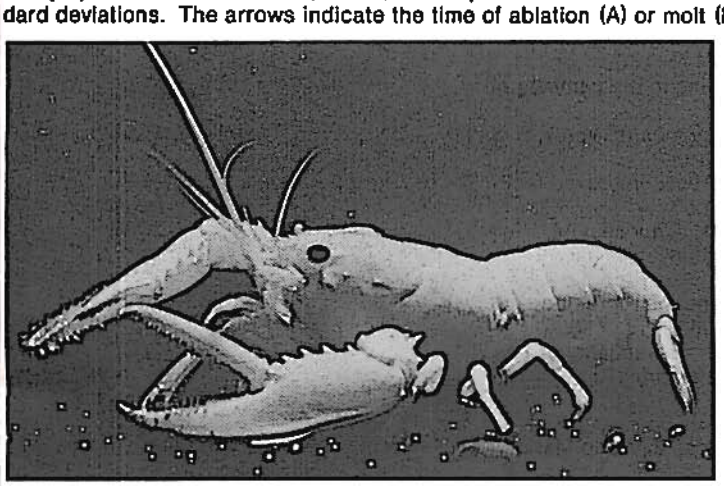


Figure 4. Eighteen-month-old hybrid (*H. americanus x H. gammarus*) lobster grown since it was 2 weeks old on a pigment-free purified diet.

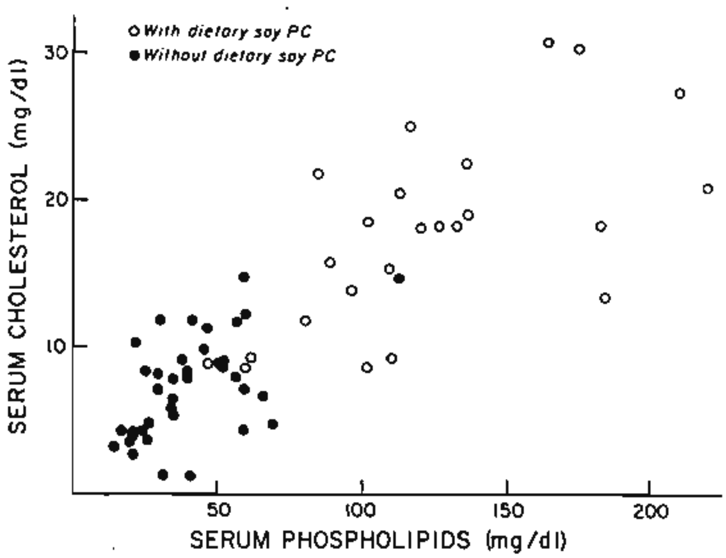


Figure 5. Relationship of total cholesterol (mg/dl) to total phospholipids (mg/dl) in the serum of juvenile lobsters fed purified diets with and without dietary soy lecithin.

Cooperating Organizations
Aquaculture Enterprises
Massachusetts State Lobster Hatchery
Seafood Specialties
UCLA, Dr. J. O'Connor

Publications

Anderson, S. L., Lynn, J. W., Yudin, A. I., and , W. H., Jr. Clark 1980. Yolk granule heterogeneity and the presence of serum lipoprotein in the ridgeback prawn, *Sicyonia ingentis*. Am. Zool. 20:839.

Bordner, C. E. and Conklin, D. E. 1981. Food consumption and growth of juvenile lobsters. Aquaculture 24:285-300.

Bucklin, A., Hedgecock, D., and Hand, C. 1980. Genetic evidence for self-fertilization in the sea anemone *Epiactis prolifera*. Am. Zool. 20:818.

Bucklin, A. C. and Hedgecock, D. In press. Biochemical genetic evidence for a third species of *Metridium* (Coelenterata, Actiniaria). Mar. Biol.

Chang, E. S. and Bruce, M. J. 1980. Ecdysteroid titers of juvenile lobsters following molt induction. J. Exp. Zool. 214:157-160.

Chang, E. S. and Bruce, M. J. 1981. Ecdysteroid titers of larval lobsters. Comp. Biochem. Physiol. 70A:239-241.

Chang, E. S. and O'Connor, J. D. In press. Observations on the metabolism and transport of carbohydrates and lipids of crustaceans. In *Biology of the Crustacea*, D. Bliss and L. Mantel, eds. Academic Press, New York.

Clark, W. H., Kleve, M. G., and Yudin, A. I. In press. An acrosome reaction in natantian sperm. J. Exp. Zool.

Clark, W. H., Jr., Lynn, J. W., Yudin, A. I., and Persyn, H. O. 1980. Morphology of the cortical reaction in the eggs of *Penaeus aztecus*. Biol. Bull. 158:175-186.

Clark, W. H., Jr., Yudin, A. I., and Kleve, M. G. 1981. Primary binding in the gametes of the shrimp, *Sicyonia ingentis*. J. Cell Biol. 91:174a.

Conklin, D. E. 1981. The nutrition of lobsters. In *The biology of the lobster, Vol. 1*, S. J. Cobb and B. F. Phillips, eds. Academic Press, New York.

Conklin, D. E., Bordner, C. E., Garrett, R. E., and Coffelt, R. J. In press. Improved facilities for experimental culture of lobsters. In *Proc. World Maric. Soc.*

Conklin, D. E., D'Abramo, L. R., Bordner, C. E., and Baum, N. A. 1980. A successful purified diet for the culture of juvenile lobsters: The effect of lecithin. Aquaculture 21:243-249.

D'Abramo, L. R. and Baum, N. A. In press. Choline requirement for the microcrustacean, *Moina macrocopa*: a purified diet for continuous culture. Biol. Bull.

D'Abramo, L. R., Bordner, C. E., Conklin, D. E., and Baum, N. A. 1981. Essentiality of dietary phosphatidylcholine for the survival of juvenile lobsters, *Homarus*. J. Nutr. 111:63-69.

D'Abramo, L. R., Bordner, C. E., Conklin, D. E., Baum, N. A., and Norman-Boudreau, K. A. 1981. Successful artificial diets for the culture of juvenile lobsters. J. World Maric. Soc 12(1):325-332.

D'Abramo, L. R., Bordner, C. E., Daggett, R., Conklin, D. E., and Baum, N. A. 1980. Relationship among dietary lipids, tissue lipids, and growth in juvenile lobsters *Homarus*. In *Proc. World Maric. Soc.*
Hedgecock, D. 1980. Exotic species in mariculture. Quarterly Review of Biology 55:294-295.
Hedgecock, D. and Nelson, K. In press. Biochemical genetic variation and adaptive strategy in the crustacea. In *Genetics, development and growth of marine animals*, V. L. Kasyanov and A. I. Pudovkin, eds. Academy of Science, Vladivostok, USSR. In Russian.
Hedgecock, D., Tracey, M. L., and Nelson, K. In press. Genetics. In *Biology of the Crustacea, Vol. 2*, D. L. Bliss and L. G. Abele, eds. Academic Press.
Kleve, M. G., Yudin, A. I., and Clark, W. H., Jr. 1981. Early events of gamete interaction in the prawn *Sicyonia ingentis* (natantia). In *Advances in invertebrate reproduction*, W. H. Clark, Jr. and T. S. Adams, eds. Elsevier/North-Holland, New York.
Lynn, J. W. 1981. The reproductive biology and gamete interaction in the freshwater prawn *Macrobrachium rosenbergii*. Ph.D. Dissertation, University of California, Davis.
Lynn, J. W. and Clark, W. H., Jr. 1980. Sperm morphology and early gamete interaction in the prawn *Macrobrachium rosenbergii*. Am. Zool. 20:875.
Lynn, J. W. and Clark, W. H., Jr. 1981. An examination of gamete interaction in the prawn *Macrobrachium rosenbergii*. J. Cell Biol. 91:175a.
Mastro, E., Chow, V., and Hedgecock, D. In press. *Littorina scutulata* and *Littorina plena*: sibling species status of two prosobranch gastropod species confirmed by electrophoresis. In *The veliger*.
Redfield, J. A., Hedgecock, D., Nelson, K., and Salini, J. P. 1980. Low heterozygosity in tropical marine crustaceans of Australia and the trophic stability hypothesis. Marine Biological Letters 1:303-313.
Sandifer, P. A. and Lynn, J. W. 1981. Artificial insemination of caridean shrimp. In *Advances in invertebrate reproduction*, W. H. Clark, Jr. and T. S. Adams, eds. Elsevier/North-Holland, New York.
Shigekawa, K. J., Clark, W. H., Jr., Yudin, A. I., and Kleve, M. G. 1980. Morphological changes in the sperm of the ridgeback prawn *Sicyonia ingentis* prior to and during gamete interaction. Am. Zool. 20:875.
Yudin, A. I., Clark, W. H., Jr., and Kleve, M. G. 1980. Gamete binding in *Sicyonia ingentis*: primary and secondary. Am. Zool. 20:875.
Yudin, A. I., Diener, R. A., Clark, W. H., Jr., and Chang, E. S. 1980. Mandibular gland of the blue crab *Callinectes sapidus*. Biol. Bull. 159:760-772.
Yudin, A. I., Kleve, M. G., and Clark, W. H., Jr. 1981. Sperm of the ridgeback prawn *Sicyonia ingentis* (natantia). In *Advances in invertebrate reproduction*, W. H. Clark, Jr. and T. S. Adams, eds. Elsevier/North-Holland, New York.

CONTROL OF REPRODUCTION IN THE DECAPOD CRUSTACEANS

University of California, Riverside
R/A-29
1980-81

Prudence Talbot

Our overall project objective is to acquire an understanding of the basic mechanisms involved in decapod fertilization and ovulation and to develop methods for controlling these reproductive processes in commercially important crustaceans. The lobster *Homarus americanus* has been our primary model in these studies.

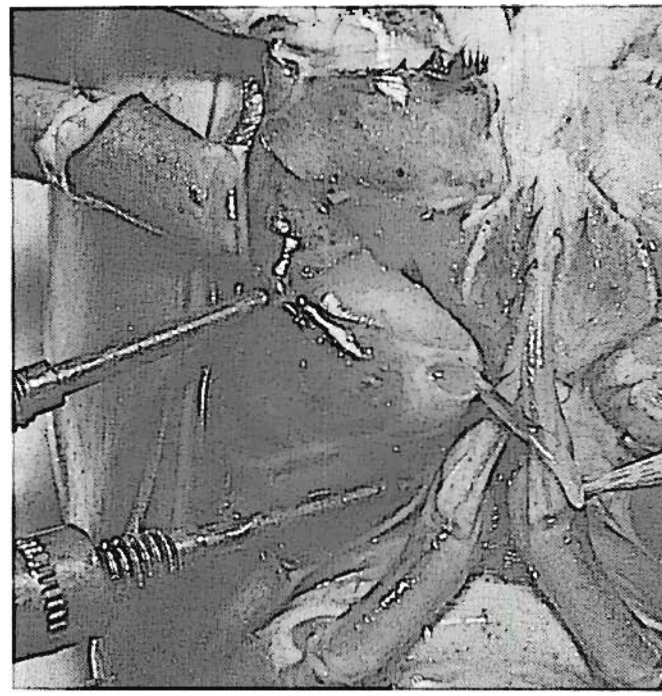
In previous years, we analyzed the structure and acrosome reaction of mature sperm from *Homarus*. Ionophore A23187 induces acrosome reactions in these sperm. This year we found a positive histochemical reaction in the acrosome for proteinases; this suggests that proteolytic enzymes are required for sperm to penetrate the oocyte's investing coat (chorion). This work has given us insight into mechanisms which may be important in lobster fertilization and also provides baseline information essential to our current studies on sperm storage.

Lobster sperm are transferred to the female receptacle in a packet termed the spermatophore. We have analyzed the ultrastructure of freshly extruded spermatophores, and have developed a technique for electrically stimulating their release from living male lobsters. We have collected data on repeated extrusions from males over a 5-year period. Males will release spermatophores in consecutive trials 1 week apart, but successful extrusions appear to be less during the summer months. We have also noted infected areas in the vas deferens of some males; these infections interfere with extrusion, and unless treated such a male would probably be sterile.

Ovulation or release of mature oocytes into the lumen of the ovary is a key event in lobster reproduction. We have developed a technique to induce *in vitro* ovulation of oocytes in seawater solutions containing the enzyme collagenase. This procedure has been helpful in our analysis of ovulatory mechanisms in lobsters and may provide a source of oocytes for *in vitro* fertilization. The procedure only works well on ovaries which are mature and probably close to natural ovulation. We do not yet know if oocytes ovulated in this manner are fully mature and fertilizable.

To understand factors involved in ovarian maturation and ovulation, we are undertaking series of morphological studies on the lobster ovary. Scanning and transmission electron microscopy have been used to analyze the structure of the mature ovary. The overall ovarian architecture has been determined to be comprised of 1) an outer muscular wall, 2) extensions of the wall (muscle cells and blood vessels), 3) mature and immature follicles, and 4) epithelial cells. The wall muscles are of interest as they contain primarily microtubules rather than actin and myosin; their physiology deserves further study. The wall muscles send extensions to the mature follicles. While we do not yet know the complete significance of this observation, it is intriguing as it suggests that a contractile mechanism may be involved in lobster ovulation. Similar contractile cells are present in ovarian follicles of many phyla. We have also analyzed in detail the structure of the mature follicle and the formation of the chorion. These observations have been valuable in extending our understanding of ovarian processes in the lobster. We hope to eventually achieve precise control of the time of ovulation. We have also begun morphological analysis of several ovaries in early stages of maturation.

We would like to develop a method for long-term storage of lobster sperm. All our efforts to freeze sperm have been unsuccessful; morphological damage is always noted in the acrosome. However, we are currently experimenting with alternate approaches. Whole spermatophores are being stored in our laboratory at 4°C. Several have been analyzed for sperm viability after 1-6 months of storage. Viability is determined by assessing sperm for 1) morphologically normal appearance with phase contrast microscopy and transmission electron microscopy, 2) ability to exclude trypan blue, and 3) ability to undergo normal acrosomal reactions. Our pilot data suggest that this procedure will enable us to hold viable sperm for extended times at 4°C.



Figures 1a and 1b. Photograph showing the ventral surface of the female lobster and the extrusion of a spermatophore through gonopore in response to an electrical stimulus. (M. Kooda-Cisco)

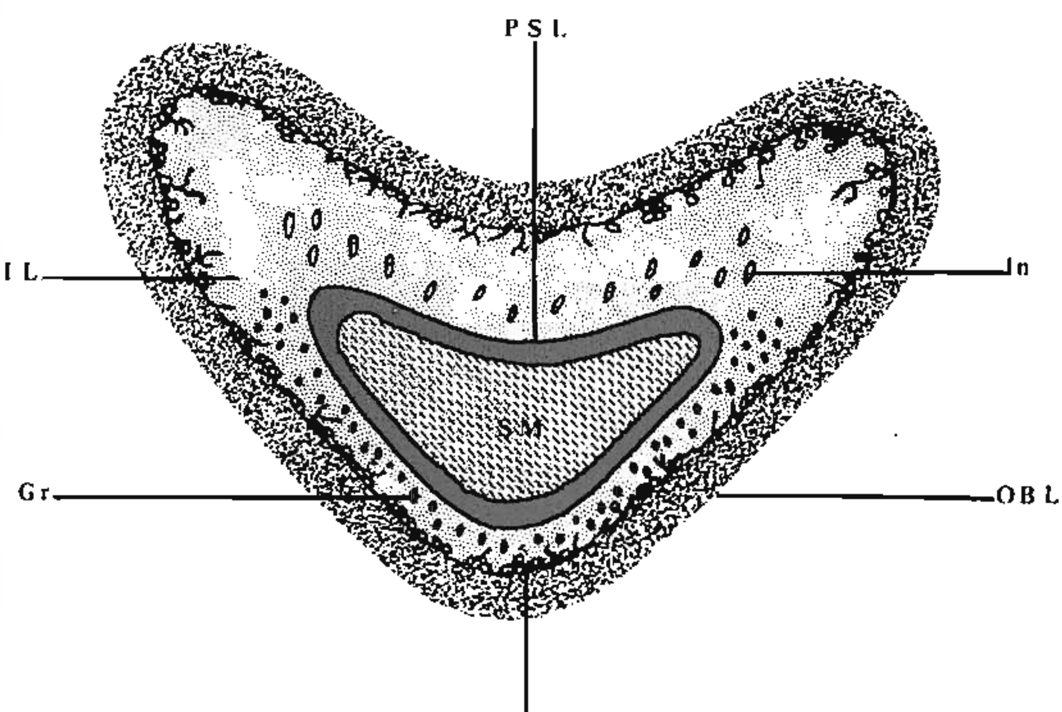


Figure 2. Schematic diagram of the lobster spermatophore in cross section. SM = sperm mass, PSL = primary spermatophore layer, IL = intermediate layer, In = inclusions, Gr = granules, N = network of acellular processes, OBL = outer bounding layer. (M. Kooda-Cisco)

Figure 3. Scanning electron micrograph showing the muscular wall (W) of the lobster ovary and muscular extensions (E) of the wall. These extensions insert on mature follicles. (P. Talbot)

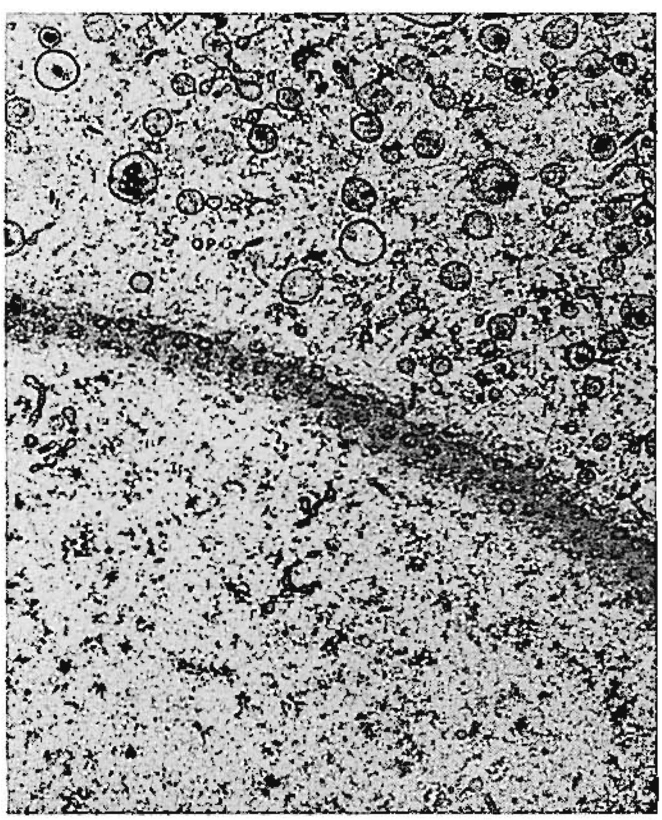


Figure 4. Scanning electron micrograph showing epithelium (E), immature follicles (I), and mature follicles (M) in a lobster ovary. Numerous "threads" pass among the mature follicles; these are muscle extensions as shown in figure 2. They may have a role in ovulation. (P. Talbot)

Figure 5. Transmission electron micrograph of the chorion surrounding a mature lobster oocyte. The chorion contains a number of "bottle-brush" structures whose function is not yet known. It is thought that sperm contain a proteinase which helps them digest a path through this barrier. (P. Talbot)

Cooperating Organizations
Bodega Marine Laboratory
Market Basket Seafood Department, Riverside

Publications

Kooda-Cisco, M. 1981. An examination of spermatophores from the lobster, *Homarus americanus*. Ph.D. thesis, University of California, Riverside.

Kooda-Cisco, M. and Talbot, P. 1980. A structural analysis of the spermatophore from the lobster, *Homarus americanus*. J. Cell Biol. 87:131a.

Kooda-Cisco, M. and Talbot, P. 1981. Electrical stimulation induces extrusion of spermatophores from the lobster, *Homarus americanus*. Abs. World Maricult.

Talbot, P. 1980. Collagenase solutions induce lobster ovulation *in vitro*. J. Cell Biol. 87:130a.

Talbot, P. 1981. Collagenase solutions induce lobster ovulation *in vitro*. J. Exp. Zool. 216:181.

Talbot, P. In press. 1981. The ovary of the lobster, *Homarus americanus*. I. Architecture of the mature ovary. J. Ultrast. Res.

Talbot, P. In press. 1981. The ovary of the lobster, *Homarus americanus* II. Structure of the mature follicle and origin of the chorion. J. Ultrastr. Res.

CULTURE OF MARINE BIVALVES: EFFECTS OF THE UPTAKE OF AMINO ACIDS

University of California, Irvine
R/A-33
1980-81

Grover C. Stephens

Dr. Donal T. Manahan and I have succeeded in producing bacteria-free suspensions of the larvae of *Crassostrea gigas* and maintaining them in the laboratory for periods of up to 10 days. We have verified the absence of bacteria by liquid culture medium techniques and also have implemented a direct method using epifluorescence microscopy.

We have shown in a preliminary way that such suspensions take up ^{14}C-labeled amino acid substrates provided in the medium. Using high performance liquid chromatography (HPLC) we have shown there is a net influx of amino acids from an ambient concentration of 0.25 uM for aspartic acid, serine, and glycine. These are major naturally occurring amino acids in seawater.

We have collected samples and conducted the analyses of seawater systems at a commercial hatchery and at a research-oriented aquaculture facility at key points from intake to culture tanks. This work is being prepared for publication.

James Davis, the Sea Grant trainee associated with this project, has succeeded in develping another bacteria-free larval suspension which we will use for comparative purposes.

Michael Rice, the Sea Grant trainee until April 1, 1981, submitted his M.S. thesis based on his work as a trainee and was awarded that degree.

Cooperating Organizations
Pigeon Point Aquaculture Center
UC Marine Biology Lab

Publications

RICE, M. A. 1981. Amino acid transport in European flat oysters, *Ostrea edulis*. M.S. thesis, University of California, Irvine.

RICE, M. A., WALLIS, K., AND STEPHENS, G. C. 1980. Influx and net flux of amino acids into larval and juvenile European flat oysters, *Ostrea edulis* (L.). J. Exp. Mar. Biol. Ecol. 48:51-59.

STEPHENS, G. C. In press. Dissolved organic material and the nutrition of marine bivalves. In *Proceedings of the Second International Conference on Nutrition in Aquaculture*. World Mariculture Society. Delaware, November 1981.

AN EXPLORATORY STUDY OF THE VEGETATIVE PROPAGATION OF BENTHIC MARINE ALGAE

University of California, Santa Barbara
R/A-37
1980-81

Aharon Gibor and Michael Neushul

We undertook an exploratory study to examine the possibility of applying the modern plant propagation techniques, such as tissue and cell culture, to commercially important marine algae. These procedures provide obvious advantages for genetic improvement and propagation of desirable new varieties of plants. We concentrated our effort during the first year of the project on developing procedures for obtaining axenic algal material. Bacteria-free cultures are a prerequisite for any further manipulations which necessitate the addition of organic nutrients to the cultures. We were successful in axenically growing several important algae.

The basic procedure which we adapted consists of physical scrubbing of the algal surface by ultrasound combined with a chemical treatment with a mild antiseptic agent. Iodinated polyvinyl pyrrolidone (Betadine) proved to be a most promising antiseptic reagent for use with these algae. Further treatment with a mixture of antibiotics was necessary for producing sterile tissues.

The usefulness of this procedure for obtaining axenic algal material for physiological and biochemical studies cannot be overemphasized. We subsequently concentrated our efforts on developing procedures for dissociating the sterile tissues and obtaining viable cell suspension. We worked primarily with the red alga *Porphyra*. We started with this plant because of its commercial importance, especially in Japan, and because we felt that it should be simpler to dissociate a two-dimensional piece of tissue than a bulky algal thallus.

At the same time we also started to study the growth requirements of the axenic tissues. We grew small fragments, rather than isolated cells, of tissue in different culture media. In these cultures we obtained two types of growth patterns. Some tissues developed many new plantlets of the leafy-thalli type. From other tissues only the conchocelis type of growth appeared, while on other tissue fragments both leafy-thalli and conchocelis grew. We still do not know the physiological conditions which determine one pattern of growth or the other.

We were also successful in isolating live cells from the leafy thalli. These isolated cells could be induced to grow and form new plantlets. We did not yet succeed in obtaining proliferation of isolated cells in suspension.

Our studies with *Porphyra* are very encouraging and indicate the feasibility of using these cultivation techniques for further studies on the commercially important algae.

Publications

GIBOR, A. 1980. Studies on vegetative propagation of benthic marine algae. In *Pacific seaweed aquaculture*, I. A. Abbott, M. S. Foster, and L. F. Eklund, eds. California Sea Grant College Program, La Jolla, California.

GIBOR, A., BINIAMINOV, M., AND NEUSHUL, M. 1980. Exploratory studies of vegetative propagation of marine algae; Procedure for obtaining axenic tissues. In *Proceedings of the Xth international seaweed symposium.* Goteburg, Sweden.

GIBOR, A., BINIAMINOV, M., AND POLNE, M. Propagation of *Porphyra perforata*: I. Axenic cultures from fragments of thalli. II. Cultures from dispersed vegetative cells. (Submitted).

POLNE, M., GIBOR, A., AND NEUSHUL, M. 1980. The use of ultrasound for the removal of macro-algal epiphytes. Botanica Marina 23:731-734.

POLNE, M., NEUSHUL, M., AND GIBOR, A. 1980. Growing *Eucheuma uncinatum* in culture. In *Pacific seaweed aquaculture*, I. A. Abbott, M. S. Foster, and L. F. Eklund, eds. California Sea Grant College Program, La Jolla, California.

POLNE, M., NEUSHUL, M., AND GIBOR, A. 1980. Studies on the domestication of *Eucheuma uncinatum*. In *Proceedings of the Xth international seaweed symposium.* Goteburg, Sweden.

PROTECTIVE MEASURES AGAINST *FUSARIUM* DISEASE IN SHRIMP

San Diego State University
R/A-38
1980-82

James F. Steenbergen and Donald V. Lightner

Considerable interest has recently developed in the mass culture of marine shrimp (*Peneaus* sp.), primarily due to the successes of the commercial pilot plants using greenhouse runways in Puerto Penasco, Sonora, and Hawaii, and the pond culture techniques used in southern Texas by the Texas A & M University Marine Station and by Ralston Purina Company in Central America. One of the major problems encountered in shrimp mariculture is disease; the most serious of the known diseases is infection by the fungus *Fusarium solani.*

One approach to the *Fusarium* problem is to immunize the shrimp against infection. In earlier Sea Grant-funded research, we developed techniques for the immunization of the American lobster, *Homarus americanus*, against the bacterial pathogen, *Aerococcus viridans* (Schapiro *et al.*, 1974; Schapiro and Steenbergen, 1974). Our overall goal in this project was to apply these lobster immunization techniques to shrimp.

Our major goals in the first year of the study were to adapt our *in vitro* phagocytosis assay for use in shrimp and to develop techniques for preparation of *Fusarium* vaccines. The major goal for the second year was to test the efficacy of these vaccines.

The most significant obstacle to the direct application of the *in vitro* phagocytosis techniques to shrimp was the smaller volume of hemolymph which could be drawn from individuals. In larger crustaceans, 2-10 ml can be routinely drawn from individuals. The equivalent volume from the size shrimp which we use (12-15 gm) is about 0.1-0.2 ml. We have developed a microscale slide technique for working with these small samples. Hemolymph samples are withdrawn from the shrimp into a syringe containing a balanced salts solution. Aliquots (0.1 ml) of the diluted hemolymph are placed onto glass microscope cover slips and the hemocytes are allowed to adhere to the glass. After washing, the cover slips are inverted and placed over a drop of the test antigen on a glass microscope slide. After incubation, the cover slip is washed and exmamined under the microscope.

One difficulty with using *Fusarium* macroconidia as antigens in the aforementioned technique is that, owing to the large size of the macroconidia with respect to the hemocytes, the mechanisms of attack is encapsulation rather than engulfment. Consequently, we investigated the possibility of using a respirometric assay of the hemocyte-antigen interaction. The rate of respiration before and after addition of antigen particles to the hemocyte suspension provides an index of the extent of phagocytic interaction. Unfortunately, the technique can only be used with pooled hemolymph because only small volumes are available from individual shrimp. Therefore, the slide technique was used for most of these studies.

We have recently developed a very promising new technique for the study of *in vitro* phagocytosis. In this technique, the test antigen is labeled with radioactive iodine-125. The radioactivity associated with hemocyte monolayers after incubation with the antigen, with reference to appropriate controls, is a direct measure of phagocytosis.

Different species of peneaid shrimp have marked differences in their susceptibility to *Fusarium* infections. *P. stylorostrus* is susceptible to *Fusarium* disease by epicuticle lesions, but is comparatively resistant to injected macroconidia. For this reason, we used this species for assessment of the comparative antigenicity of killed and live vaccines. Because of the rather general nature of invasion in *Fusarium* infections, an avirulent vaccine may not be possible for the more susceptible, but more economically desirable, species of shrimp, such as *P. japonicus*.

The optimum temperature for *in vitro* phagocytosis was determined to be 25°C (figure 1). This correlates well with the optimum growth temperature, and serves as a warning to mariculturists: the use of elevated temperatures to achieve higher growth rates may also lead to increased disease problems (Steenbergen *et al.*, 1978).

Heat-killed vaccines were used for most of the work due to the difficulty of obtaining consistent results with avirulent cultures. Heating *Fusarium* spore suspensions for 10 min at 55°C results in complete loss of viability.

The effect of immunization of *P. stylorostrus* with *Fusarium* vaccines is shown in figure 2. There is a marked rise in the phagocytic index which reaches a maximum in about 6 days after injection. This rise in phagocytic index correlates well with increased resistance to challenge with lethal doses of *Fusarium solani.* There is also a corresponding decrease in the time required for clearance of injected spore suspensions from the hemolymph of immune animals. There is no fungicidal activity in the cell-free hemolymph either before or after immunization, so the response is entirely cellular.

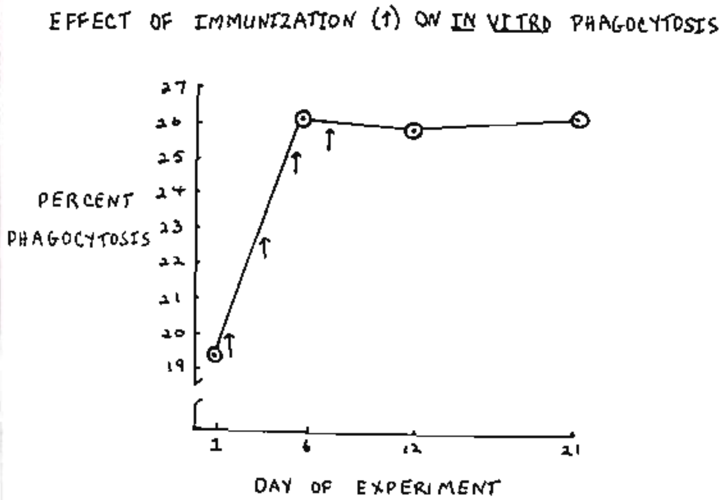


Figure 1. Effect of Immunization (↑) on *In Vitro* Phagocytosis

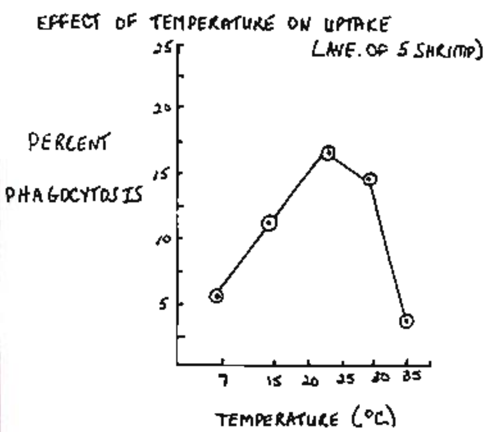


Figure 2. Effect of Temperature on Uptake (Avg. of 5 shrimp)

Cooperating Organizations
Coca Cola
Environmental Research Laboratory, Tucson
Ikko Hawaii Aquaculture Company
Texas A & M University
University of Arizona

References

Schapiro, H. C. and Steenbergen, J. F. 1974. Active immunity to gaffkemia in lobsters. In *Fifth Annual Meeting, World Mariculture Society.*

Schapiro, H. C., *et al.* 1974. Gaffkemia in the California spiny lobster, *Panulirus interruptus*: infection and immunization. Aquaculture 3:403-408.

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

Publications

Slivka, S. R. 1982. In vitro phagocytosis in the shrimp *Peneaus stylirostris.* M.S. thesis, San Diego State University.

Slivka, S. R. and Steenbergen, J. F. Effects of immunization on *in vitro* phagocytic activity of shrimp hemocytes. Presented at the southern California branch of the American Society for Microbiology annual meeting, October 1981.

Slivka, S. R. and Steenbergen, J. F. *In vitro* phagocytosis by shrimp (*Peneaus stylorostrus*) hemocytes. Aquaculture. (Submitted).

ASSESSMENT OF SPERM-EGG INTERACTIONS DURING FERTILIZATION AND HYBRID FORMATION OF CALIFORNIA ABALONES

University of California, San Diego/
Scripps Institution of Oceanography
R/A-39
1980-81

Victor D. Vacquier

Our 1980-81 objectives were to biochemically characterize the gamete components important to abalone fertilization and to promote fertilization of heterologous gametes, ultimately producing hybrid abalones. We studied the factors preventing heterologous gamete fertilization and the differences between conspecific and hybrid abalone.

Gametes

The morphology of *Haliotis rufescens* spermatozoa has been described before and after occurrence of the acrosome reaction (AR) (Lewis *et al.*, 1980). The AR is necessary for release of sperm products that break down the egg vitelline layer (VL) and for subsequent fusion of the sperm to the egg plasma membrane during fertilization. Exocytosis of the acrosome granule from within the bullet-shaped sperm occurs first, followed immediately by extension of the acrosome process.

A soluble sperm protein dissolves the egg VL (Talbot *et al.*, 1980; in prep.). The purified sperm lysin is about 10,400 daltons subunit molecular weight. We isolated and characterized the egg VL because it is the natural substrate of the sperm lysin. VLs are approximately 64% carbohydrate and 36% protein, containing a large proportion of fucose and threonine. Hundreds of milligrams of the pure lysin and VLs can be obtained with ease.

Lysin's mechanism of action is not clear. Lysis is temperature- and concentration-dependent, and activity is lost when boiled. Lytic activity was not blocked by myriad protease inhibitors, nor did it act on a variety of synthetic substrates. Other highly positively charged molecules do not lyse the VL. Lytic activity appears to be accompanied by inactivation of the lysin. Lysin activity may not be enzymatic or due to a charge effect. Instead, lysin may bind to a small linker molecule in the VL that releases large molecular weight repeating subunit molecules.

The purpose of another study was to determine whether cyclic nucleotides (cN) play some role in the induction of the AR and whether levels of these cN could be modulated by extracellular Ca^{2+}.

Addition of exogenous Ca^{2+} induces the AR in abalone sperm. Ca^{2+} also appears to play a primary role in the elevation of sperm cN levels and in induction of the AR by biological factors in other species of sperm. We observed that methylxanthines (MX), which are known in many cell types to inhibit cN phosphodiesterases, were effective in inducing the AR.

We found that Ca^{2+} added to abalone sperm elevates cAMP levels, MX in the absence of Ca^{2+} elevates cAMP levels and that synergistic increases (up to 200 fold) occur when both are added. The time course of these agents on cN were identical to their effects on the AR. Our data suggests that 1) extracellular Ca^{2+} is intimately related to the cN metabolism of abalone sperm, 2) cN may play some role in the AR, but is probably not the primary mediator, and 3) MX effects on cN metabolism may be partially due to interactions with adenyl cyclases and CN phosphodiesterases, but 4) are primarily due to their ability to alter Ca^{2+} transport (Kopf *et al.*, 1981; a, b, in prep.).

Sperm-Egg Interaction

From 1 to 100 initial sperm contact the VL, acrosome react, and enter the VL. Most nonfertilizing sperm are reversibly bound at the VL and do not acrosome react. The sperm that enter the VL continue to swim across the perivitelline space. Only the first spermatozoan contacting the oolemma fuses with the egg. Therefore, blocks to polyspermy of homologous fertilization occur at two levels: 1) the VL and 2) the oolemma (Lewis, in prep.).

We have found that fertilization by heterologous gametes is more tenuous than by homologous gametes. Eggs are receptive to heterologous sperm for only a short time after spawning and must be surrounded by a critical minimum number of those sperm. Heterologous sperm have no difficulty traversing the egg jelly and reversibly attaching to the VL, but they do have difficulty traversing the VL. This may be due to some partial species-specificity of sperm lysin. If heterologous lysin is not as effective as homologous lysin, a critical minimum number of sperm releasing heterologous lysin may overwhelm the VL reactive sites, thus, weakening the VL sufficiently for some sperm to enter.

These aspects have been examined further through controlled fertilizations using homologous and heterologous gametes.

Controlled Fertilizations

In all spawning experiments (21 dates) gametes were collected through concurrent spawning of *H. rufescens*, and either *H. fulgens*, *H. corrugata*, or *H. sorenseni*. In addition, several hybrids from wild and cultured stocks were spawned for back-cross and F_1 x F_1 combinations.

Under the conditions of our experiments (Leighton and Lewis, in prep.), the concentration of sperm yielding maximum fertilization with least abnormality in subsequent development was approximately 10^5 sperm/ml for homologous combinations, and 10^7 sperm/ml for heterologous fertilizations (figure 1). Concentrations greater than 10^7 sperm/ml generally caused lysis of the VL with subsequent abnormal development.

Early combination of eggs with sperm was essential to maximum hybrid fertilization. Eggs fertilized by heterologous sperm within 5 minutes of release generally displayed 40-80% development, but after 60 minutes, yielded less than 20% cleaving eggs. In contrast, success of homologous fertilizations was usually greater than 90% even when gametes were combined 2 hours after spawning (figure 2).

Rapid development of blocking mechanisms with nonspecific effects was studied by a two-step fertilization procedure (Leighton and Lewis, in prep.). Freshly spawned eggs, first combined with heterologous sperm, and then 30 minutes later exposed to homologous sperm, exhibited no marked increase in percentage development over that for eggs fertilized by heterologous sperm alone. Control homologous zygotes proceeded to develop in large numbers. An example is provided for a cross of *H. rufescens* with *H. fulgens* (table 1). These results suggest that the block established in the presence of "foreign" sperm precludes significant fertilization by "same" sperm. Once used for hybrid production, excess unfertilized eggs may not be salvaged as nonhybrid zygotes. We are now examining this subject in detail.

Success of Hybrid Production

Spawning and the success of fertilization are summarized in table 2. In addition to the four primary California abalone species studied, hybrids were back-crossed with parental species and hybrids were crossed with like and unlike hybrids. The back-cross of *H. rufescens/H. walallensis* female x *H. rufescens* male yielded juvenile progeny which exhibited phenotypic characters distinguishable in a ratio of 1:1, suggesting simple Mendelian inheritance. Crosses of F_1 *H. rufescens/H. fulgens* to give F_2 larvae yielded juveniles separable by species and hybrid characters in the ratio 1:2:1 (Leighton and Lewis, in prep.).

Larvae from homologous and heterologous fertilizations (and reciprocal crosses) were cultured through metamorphosis to juvenile stages. Growth of representative groups of cultured conspecific and hybrid progeny has been followed to at least 1 year (table 3). Some combinations suggest improved growth rates (e.g., *H. rufescens* x *H. sorenseni*), while others exhibited improved survival rates (e.g., *H. rufescens* x *H. corrugata*). Survival of conspecific *H. corrugata* in culture is often very low (ca. 0.1%), but hybrid *H. rufescens* x *H. corrugata* in this study have shown remarkable vitality (survival 3.3%).

Planned research includes experiments to study the nature and control of hybrid block mechanisms, to test the growth and survival of hybrids to special culture and environmental conditions, and to explore the genetics and fertility of hybrids through back-cross and F_1 x F_1 combinations.

Table 1

Two-step Fertilization of Red Abalone Eggs with Conspecific and Heterospecific Sperm

Female	Male(s)	Fertilization First (Minutes after Egg Release)	Fertilization Second (Minutes after Egg Release)	% Development
Series I				
Red	Green	8	-	23.1
Red	Green + Red	8	40	26.2
Red	Red	10	-	85.3
Series II				
Red	Green	45	-	4.0
Red	Green + Red	45	75	7.3
Red	Red	50	-	64.6

In this experiment, *H. rufescens* (red) eggs were promptly fertilized (Series I) by *H. fulgens* (green) sperm, or for the conspecific control, by red sperm. After flushing excess sperm, one hybrid-fertilized group (ca. 500 eggs) was combined with red sperm 30 minutes later. In the Series II experiment eggs were aged for 45-50 minutes before first fertilization.

Table 2

Gamete Combinations and Fertilization Success[1]

Female x Male		Number of Spawnings	Development %[2] Average	Range	Remarks
Conspecific					
R	R	17	92.8	82.4-100.0	Standard control; poor success in summer
G	G	2	94.0	93.0-95.0	Few crosses less than 1 hr.
P	P	3	89.2	86.5-94.2	Few crosses less than 2 hr.
S	S	0	-	-	Spawning of both sexes not coincident
Heterospecific					
R	G	8	32.1	21.7-53.3	ca. 0.1% survival of juveniles
R	P	4	16.4	4.3-24.0	ca. 5% survival of juveniles
R	S	1	19.4		ca. 5% survival of juveniles
G	R	4	29.8	9.5-61.1	ca. 1% survival of juveniles
G	P	3	36.1	9.0-72.3	ca. 1% survival of juveniles
P	R	10	23.2	7.5-45.7	ca. 5% survival of juveniles
P	G	7	35.0	10.5-84.3	ca. 0.1% survival of juveniles
S	R	1	98.7		Highest fertilization rate; ca. 5% survival of juveniles
Hybrid crosses					
R	GR	1	6.0		ca. 0.1% survival of juveniles
S	GR	1	26.4		ca. 0.1% survival of juveniles
RW[3]	R	1	41.4		ca. 5% survival of juveniles
RW[3]	GR	1	4.8		ca. 0.1% survival of postlarvae
GR	R	1	34.9		ca. 0.1% survival of postlarvae
GR	GR	2	22.5	6.0-38.9	ca. 0.01% survival of juveniles

[1]Fertilizations were all within 1 hour of egg release. R = *H. rufescens*, G = *H. fulgens*, P = *H. corrugata*, and S = *H. sorenseni*.

[2]Measured at 4-16 cell stage.

[3]RW = *H. rufescens* x *H. walallensis* hybrid female from field collection.

Table 3

Sizes of Laboratory-reared Conspecific and Hybrid Abalone at 1 Year of Age

Combination			Size at 1 Year (mm)		
Female	Male	n	Mean	Range	Source
R	R	50	15.6	9.9-20.0	Leighton, 1974
G	G	36	29.7	23.7-33.7	Leighton et al
P	P	18	18.3	12.2-26.4	Leighton, 1974
S	S	19	13.4	8.0-21.0	Leighton, 1974
G	R	61	28.0	21.2-37.4	This study
R	P	45	17.3	8.9-26.1	This study
R	S	17	24.9	15.6-33.4	This study
S	R	27	*		

*(8.4 mm at 7.5 mo., this writing date)

Postlarvae and juveniles cultured at the Scripps Institution of Oceanography and the Southwest Fisheries Center (NMFS), La Jolla.

Abbreviations as in table 2.

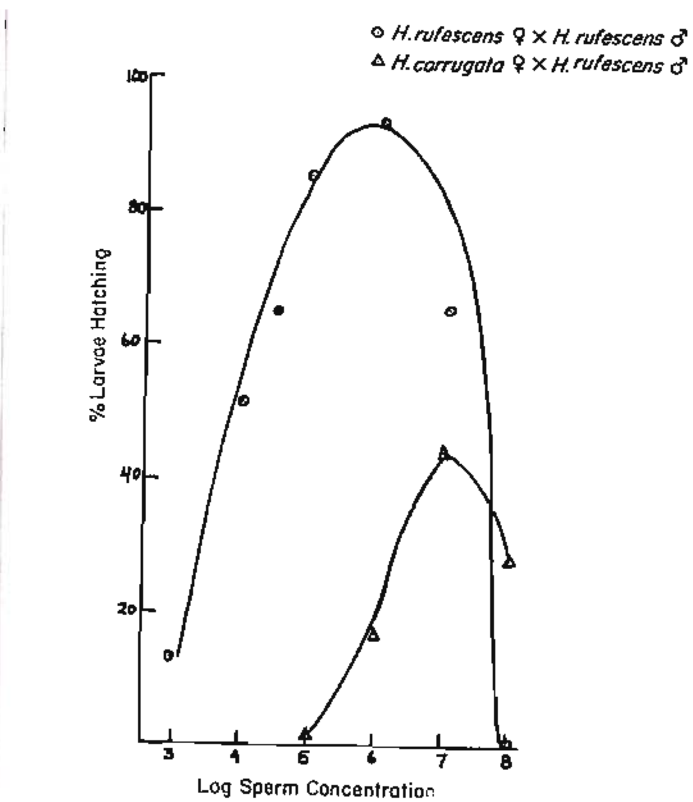


Figure 1. Effect of sperm concentration on fertilization and subsequent development.

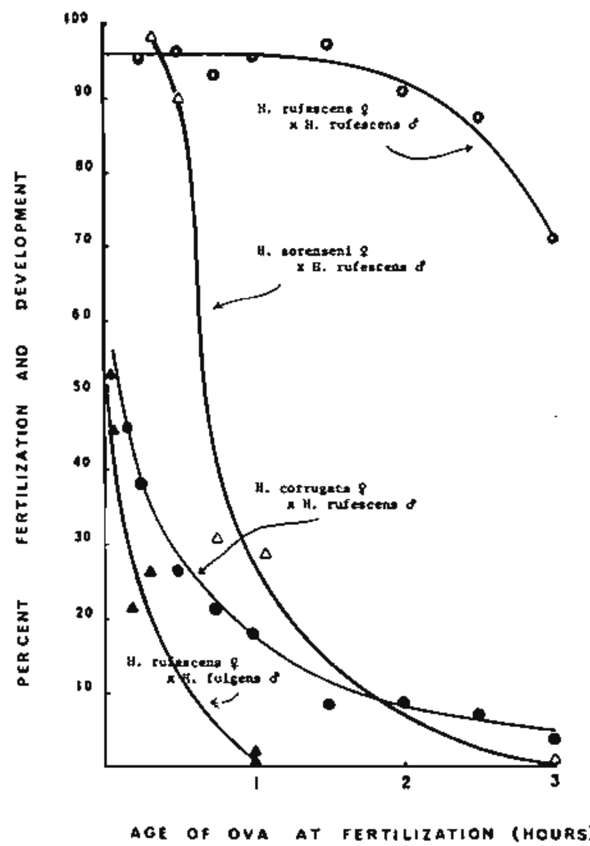


Figure 2. Success rate of homologous fertilizations.

References

KOPF, G. S., LEWIS, C. A., AND VACQUIER, V. D. 1981. Regulation of abalone sperm cyclic nucleotide metabolism and the acrosome reaction by extracellular calcium and methylxanthines. J. Cell Biol. 91:178a.

KOPF, G. S., LEWIS, C. A., AND VACQUIER, V. D. In prep. Effects of MX on abalone sperm AC and cN phosphodiesterases.

KOPF, G. S., LEWIS, C. A., AND VACQUIER, V. D. In prep. Methylxanthine-induced alterations of calcium fluxes in the spermatozoa of the red abalone, *Haliotis rufescens*.

LEIGHTON, D. L. AND LEWIS, C. A. In prep. Experimental hybridization in abalone.

LEWIS, C. A. In prep. An ultrastructural analysis of fertilization in the abalone, *Haliotis rufescens*.

TALBOT, C. F., LEWIS, C. A., AND VACQUIER, V. D. In prep. The isolation and characterization of an egg vitelline layer lysin from abalone sperm.

Publications

KOPF, G. S., LEWIS, C. A., AND VACQUIER, V. D. 1981. Regulation of abalone sperm cyclic nucleotide metabolism and the acrosome reaction by extracellular calcium and methylxanthines. J. Cell Biol. 91:178a.

KOPF, G. S., LEWIS, C. A., AND VACQUIER, V. D. In prep. Effects of MX on abalone sperm AC and cN phosphodiesterases.

KOPF, G. S., LEWIS, C. A., AND VACQUIER, V. D. In prep. Methylxanthine-induced alterations of calcium fluxes in the spermatozoa of the red abalone, *Haliotis rufescens*.

LEIGHTON, D. L. AND LEWIS, C. A. In prep. Experimental hybridization in abalone.

LEWIS, C. A. In prep. An ultrastructural analysis of fertilization in the abalone, *Haliotis rufescens*.

TALBOT, C. F., LEWIS, C. A., AND VACQUIER, V. D. In prep. The isolation and characterization of an egg vitelline layer lysin from abalone sperm.

REGULATION OF THE PRODUCTION OF DORMANT CYSTS BY THE BRINE SHRIMP, *ARTEMIA SALINA*, AND FACTORS INFLUENCING THE VIABILITY OF SUCH CYSTS

University of California, Davis
R/A-41
1980-81

John H. Crowe

Iron Transport and Cyst Production

Previous investigators have shown that female brine shrimp produce dormant cysts under the influence of environmental Fe^{+3}, reduced O_2, or elevated salinity. We have investigated the mode of interaction between these factors, and have found that the animals possess an active transport system for Fe^{+3} (figure 1), which is activated by increased salinity and decreased O_2 (figure 2). A curious feature of this transport system is that it shows distinctly sigmoidal kinetics, rather than the hyperbolic kinetics seen in most ion transport systems. We now suspect, based on these data, that induction of the production of dormant cysts may be related entirely to Fe^{+3} availability.

Cyst Hatchability

Many laboratories and commercial facilities store cysts in freezers. We have investigated the conditions under which cysts may be stored at low temperatures, with the following results. So long as the water content is $\leqslant$ 0.6 g H_2O/g dry weight, the cysts survive liquid nitrogen temperatures (figure 3). We have also shown that this fraction of the water in hydrated cysts is nonfreezable. Thus at water contents $\leqslant$0.6 g/g there is no ice formation. As an adjunct to this work, we have developed a single means for vacuum drying decapsulated cysts. The decapsulated cysts were formerly stored in concentrated brine, which is often inconvenient. Details of the method are available on request.

Recently, we have investigated intracellular pH (pH_i) in dormant cysts, and have found that pH_i is low during dormancy (ca. 6.5). When development is resumed, pH_i rapidly rises to about 7.5. Since it is now known that many metabolic processes, including glycolysis, are strongly inhibited at pH 6.5, we suspect that the maintenance of dormancy may be directly related to pH_i. Therefore, a possibility exists that cysts that show low hatchability may exhibit a low pH_i. Such cysts could be induced to hatch by artificially elevating pH_i with permeant weak bases such as NH_3. We are currently investigating these possibilities.

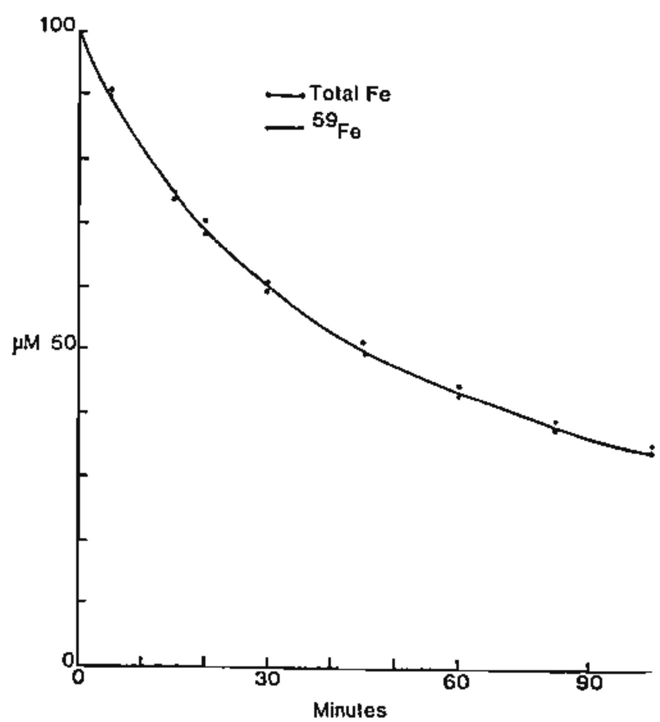


Figure 1. Fe^{+3} in the medium around adult brine shrimp as a function of time.

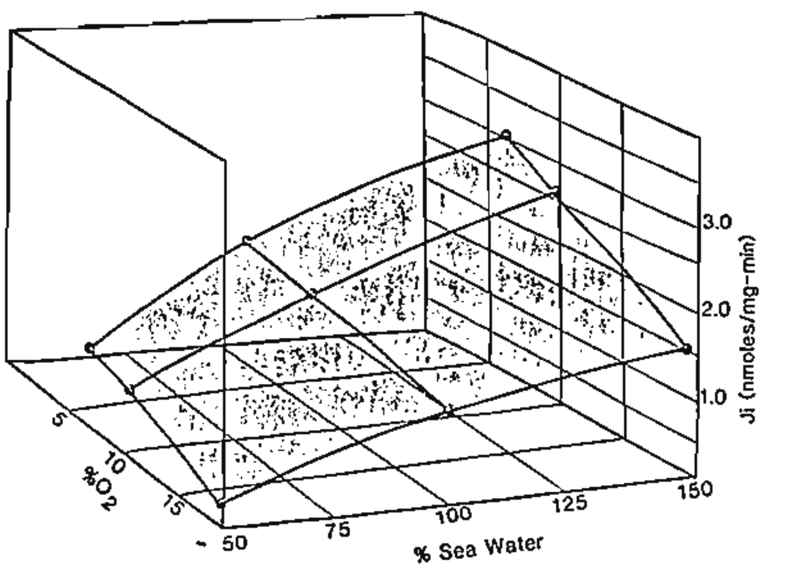


Figure 2. Effects of salinity of O_2 in the medium on the rate of influx of Fe (Ji) into brine shrimp.

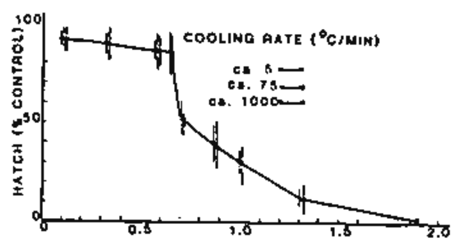


Figure 3. Effects of water content and cooling rate on survival of freezing by cysts.

Publications

BUSA, W. B., CROWE, J. H., AND MATSON, G. B. 1982. Intracellular pH and the metabolic status of dormant and developing *Artemia* embryos. Arch. Biochem. Biophys. 216(2):711-718.

CROWE, J. H. AND COOPER, L. C. In press. Uptake of iron by brine shrimp, *Artemia salina*. Molecular Physiol.

CROWE, J. H., CROWE, L. M., AND O'DELL, S. J. 1981. Ice formation during freezing of *Artemia* cysts of variable water contents. Molecular Physiol. 1:143-152.

CROWE, J. H. AND CROWE, L. M. In press. Induction of anhydrobiosis: membrane changes during drying. Cryobiology.

FOOD AND FIBER FROM SEAWATER, SAND, AND SOLAR ENERGY

University of California, Davis
R/A-42
1980-81

Emanuel Epstein

The main goal of this investigation was to examine the feasibility of using seawater or dilutions of it to raise crops specifically selected or bred for seawater culture. The project is based on the following facts. 1) There are vast stretches of coastal deserts representing a constellation of resources not now used for producing crops: expanses of sandy land, seawater and the mineral nutrients in solution in it, and solar energy. 2) Plant life is not necessarily incompatible with even highly saline conditions, as evidenced by the existence of the halophytes — wild plants that grow along the seacoast, in salt marshes, on saline desert soils, and in other saline habitats. 3) Even within crop species there exists considerable genetic variability in respect to salt tolerance. The project was designed to test whether the facts set out above can be used to generate, by selection and breeding, strains or varieties of economically useful plants capable of being raised by seawater or brackish water culture.

Crops

It was decided to use two grains, barley and wheat, and a vegetable, the tomato, in this project. Grains were chosen mainly for their importance as staple foods, and the tomato because of its high value as a cash crop not necessarily requiring large acreages for economic production.

Biological Methodology

For the grains, available sources of genetic variability were used — a composite cross for barley (Composite Cross XXI) and the world collection of wheat for this crop. Intraspecific selection showing little promise in the tomato, the domestic *Lycopersicon esculentum* was crossed with the exotic, salt tolerant *L. cheesmanii* and progeny from this cross was used.

Physical Methodology

The basic method was the same for all three crops: seeds or seedlings were salt stressed by exposure to nutrient solutions salinized with a synthetic sea salt mix. The concentrations chosen were such as to eliminate the large majority of all plants; they ranged from 50 to 90% seawater salinity. The most salt-tolerant plants were grown out for seed. These selections were then field tested at the University of California Bodega Marine Laboratory, where they were irrigated with seawater and dilutions of it. The seawater also supplied all mineral nutrients except nitrogen and phosphorus, which were furnished in the form of slow-release and conventional fertilizer. (The concentrations of these two nutrients in seawater are very low.) Figure 1 shows the Bodega site during the 1981 project year. The canopy protected the grain plots from rain so that the saline treatments would not be diluted by fresh water. The two small plastic shelters served to grow the tomato selections, the climate at Bodega Bay being too cool to grow tomatoes in the open. The tank trailer in the foreground was used to haul the seawater or dilutions of it to the site. The town of Bodega Bay can be seen in the background, beyond the bay.

Results

Table 1 shows the grain yields for the 1980 and 1981 seasons (for wheat, 1980 only).

The control (fresh water) treatments for 1980 resulted in unduly low yields, because overirrigation caused an excessive loss of nutrients. This same factor probably reduced the yields in the saline plots as well, although to a lesser extent.

The results show that selected lines of barley can be grown under brackish water irrigation, yields on the order of the world average being attainable at 33% seawater salinity, and even (1980) at 66% seawater salinity. (The latter value corresponds to 23,000 parts per million salt; in conventional irrigation agriculture, water of one tenth that salinity is considered marginal.)

Wheat, not considered to have as good a potential for salt tolerance, yielded much less, but selections nevertheless survived and produced some grain even at full seawater salinity, and higher yields in two brackish water treatments.

The tomato selections produced very flavorful tomatoes the size of cherry tomatoes at salinities up to 70% seawater, or 24,500 parts per million. The results demonstrate the feasibility of genetically transferring salt tolerance from a wild, economically useless species into a domestic variety.

Overall Assessment

Can seawater or water with a high percentage of seawater be used to raise crops specifically selected and bred for this purpose? The answer, based on this project, is yes, if the question is confined to the matter of biological feasibility. If the question is meant to include economic feasibility, the answer will depend on many factors not included in the present study: the area where the crop is to be grown; social and economic conditions; the level of expertise available; the amount and cost of fresh water available; the amount and variability of rainfall, if any, and its seasonal distribution; and finally, the availability of salt-tolerant crops tailored to the local conditions. Availability of such seed stocks will depend on consistent support for research and development on a much larger scale than was available for this pilot study. Finally, support will be needed for research on appropriate irrigation technology; drip irrigation and surge flow are two methods that particularly merit attention.

Table 1

Barley and Wheat Yields Kilogram/Hectare

		Percentage Seawater		
	Control	33	67	100
Barley, 1980	968	2390	1436	456
Barley, 1981	3643	2090	568	689
Wheat, 1980	1140	579	213	11

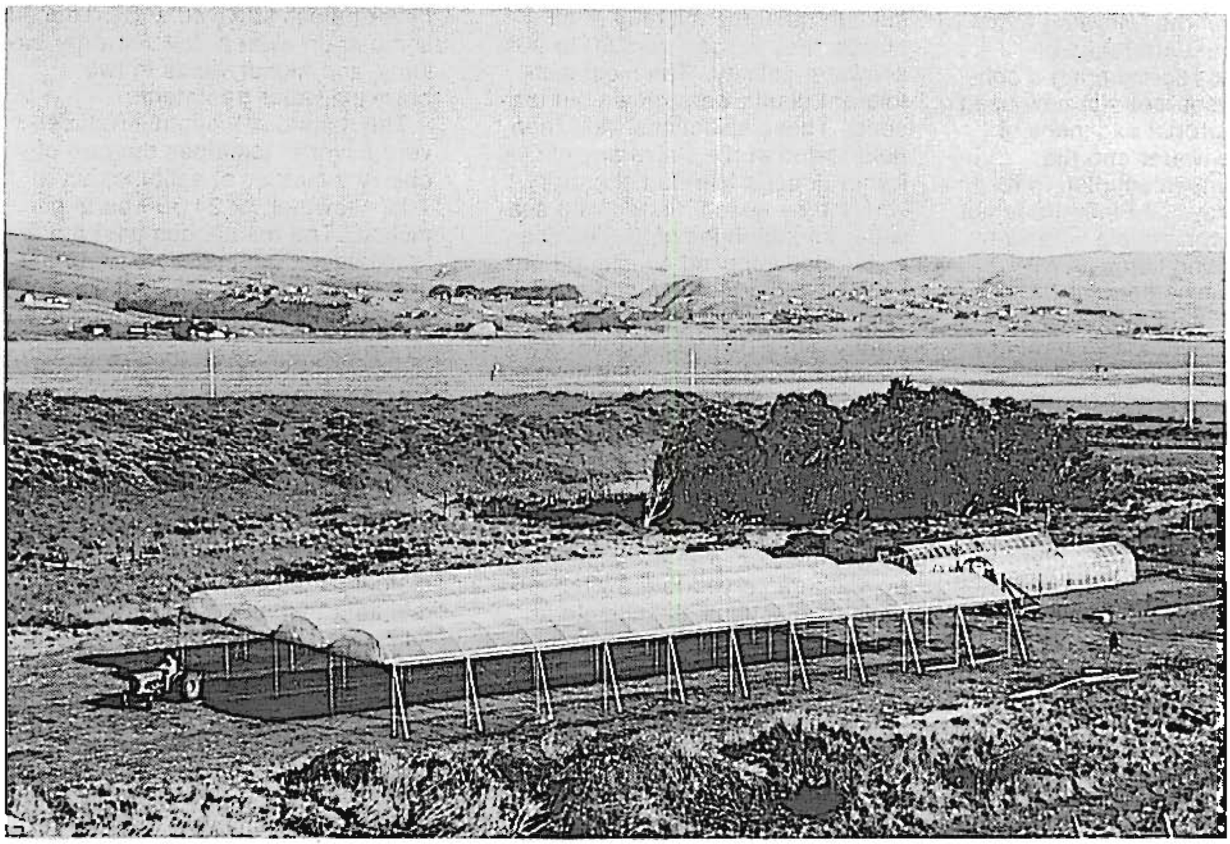


Figure 1. The field test site among the dunes at Bodega Marine Laboratory, Bodega Bay, California.

Cooperating Organizations

Coastal Commission
International Plant Research Institute, Inc.
Sonoma County Planning Commission
University of California Bodega Marine Laboratory
University of California Davis Cooperative Extension

Publications

EPSTEIN, E., NORLYN, J. D., RUSH, D. W., KINGSBURY, R. W., KELLEY, D. B., CUNNINGHAM, G. A., AND WRONA, A. F. 1980. Saline culture of crops: a genetic approach. Science 210:399-404.

RUSH, D. W. AND EPSTEIN, E. In press. Breeding and selection for salt tolerance by the incorporation of wild germplasm into a domestic tomato. J. Hort. Science.

BIOCHEMICAL ENGINEERING FOR IMPROVED PRODUCTION OF COMMERCIALLY VALUABLE MARINE SHELLFISH

University of California, Santa Barbara
R/A-43
1980-82

Daniel E. Morse

In cooperation with industry and other researchers, we have demonstrated that modern methods of biochemical research and development can be used to improve the reliability, yield, and economic efficiency of production of a large number of abalone species and hybrids and other commercially valuable molluscan shellfish. Critical life-cycle stages which thus far have proved amenable to improved control by this biochemical engineering approach include reproduction, larval settlement, metamorphosis, and the acceleration of early growth.

Analysis of the physiological and biochemical mechanisms which control reproduction in molluscs revealed a prostaglandin-dependent regulation of spawning in abalones and certain other species. Using techniques based upon this finding, we have found that spawning of gravid adults can be induced by the addition of prostaglandins to the surrounding seawater. Even more reliably and inexpensively, spawning can be induced at will by activation of the natural enzymatic synthesis of prostaglandins in gravid animals in response to added hydrogen peroxide. Peroxide activation of the prostaglandin-dependent spawning reaction has been found widely useful for obtaining synchronous and copious release of fully competent gametes (both eggs and sperm) in a large number of species of abalones, oysters, scallops, clams, and other valuable molluscs throughout the world.

We have found that the efficient induction of settlement and metamorphosis of abalone larvae normally requires the presence of specific crustose red algae which are uniquely associated with natural recruiting substrates. This requirement can be met by providing competent larvae with the essential algae or with specific proteins purified from these algae, although production of these inducers is both time-consuming and costly. Most conveniently and inexpensively, we find, this natural requirement can be met by providing the larvae with certain unique amino acid constituents normally associated with the inducing proteins. Thus, γ-aminobutyric acid (GABA) can be used simply, safely, and inexpensively to induce complete and rapid larval settlement and metamorphosis — with minimal mortality — in a number of commercially important abalone species. This and similar neurotransmitter-related, amino acid-derived compounds are proving comparably effective for the reliable induction of settlement and metamorphosis in a number of other valuable molluscan species.

From our most recent studies of the biochemical mechanisms by which the planktonic larvae detect and recognize their required environmental (biochemical) inducers, and related studies of the mechanisms by which these inducers act to induce settlement, metamorphosis, and development, we also are developing a new class of biochemical inducers of even lower cost and wider applicability.

Recent analyses of the natural requirements for rapid early postlarval growth in abalones reveal a mechanism of growth control which is susceptible to hormonal acceleration. Results of these experiments indicate that the extreme heterogeneity of sizes and growth rates generally observed in the cultivation of abalones (and other molluscs) is not the result of genetic variation, but reflects instead physiological deficiencies in cultivation which may be corrected by external biochemical control. These results also indicate that genetic breeding programs based upon selection for apparently desirable growth rate properties cannot effectively be started until the physiological and biochemical requirements for optimal growth are fully defined.

Improved Production of Abalones: Further Development and Extension of Techniques for Improved Production of Many Species and Hybrids

Working in close cooperation with representatives of industrial hatcheries, other Sea Grant-supported research programs, and public research and development efforts in the U.S. and abroad, we have expanded the application of the techniques described above to improve the production of a huge number of abalone species and hybrids (table 1).

Gametogenesis, spawning, and larval development and metamorphosis of thermophilic (warm-water) California species (the green, black, and pink abalones, which previously had proved very difficult to produce by other methods), now have been accomplished with highly efficient methods. Efficient and accelerated gametogenesis was shown to require saturation feeding at elevated temperatures; spawning was found to be reliably inducible using our hydrogen peroxide method at high temperature (ca. 20°C, rather than the previously used 15°C); and larval development, and the induction of settlement and metamorphosis using our GABA induction method, also were found to be rapid, efficient, and yielding high survival rates, when conducted at elevated temperatures (ca. 17-20°C). The increased efficiency of abalone production resulting from these techniques is illustrated in figure 1.

Successful application of our results to the efficient production of interspecific hybrids (bred for their extended range of cultivation, desired qualities of meat value, growth rate, etc.) has been demonstrated in related Sea Grant research projects under the direction of Dr. Kenneth Chew at the University of Washington, and Drs. Victor Vacquier, Jr., David Leighton, and Cindy Lewis, at the University of California, with consultation and instruction in methodology from our research group. Similar cooperative interactions with other groups in the U.S. and abroad also have proven successful.

These results thus have increased the economic efficiency of production of a large number of abalone species, they have increased the number of species and hybrids successfully cultivated, and they have significantly extended the geographic range of potentially efficient abalone cultivation.

Development of Applications for Improved Production of Other Species of Commercially Valuable Shellfish

Improved Control of Reproduction. In research which we have conducted, and in which we have cooperated with other Sea Grant-supported and locally sponsored programs in California, Washington, Oregon, Hawaii, Palau, Guam, and abroad, we and our colleagues have demonstrated that the hydrogen peroxide method we developed provides a simple, inexpensive, and reliable means for spawning many valuable shellfish species: abalones, oysters, giant scallops, mussels (*Mytilus*), giant clams, limpets, top snails, turban snails, mussels (*Branchidontes*), and clams.

Species induced to spawn by this method include several with which other induced-spawning methods had not been reliable.

Improved Control of Larval Settlement and Metamorphosis. In our detailed biochemical analysis of the mechanisms by which planktonic molluscan larvae detect required inducers and recognize suitable and inducing substrates on which settlement and metamorphosis occur, we have determined that the inducers of a large number of valuable species are protein-linked, amino acid-derived, neurotransmitter-related compounds associated with the normal recruiting surfaces. We have found that these complex, protein-linked substances, or, in many cases, the simple, amino acid-derived, neurotransmitter-like active analogs themselves, are required for the efficient induction of rapid settlement and metamorphosis with high survival rates. In our most recent research and in cooperation with other researchers and Sea Grant-supported programs in California, Washington, Oregon, Hawaii, Guam, Delaware, Maryland, Massachusetts, and Florida, we and our colleagues have found that such amino acid-derived inducers (such as GABA and DOPA) and their protein conjugates induce settlement and metamorphosis of larvae of a number of economically important gastropod and bivalve molluscs and other marine invertebrates, as shown in table 2.

While the use of GABA provides an inexpensive, convenient, and fully reliable means for complete induction of settlement and metamorphosis of a large number of abalone and other valuable species, the development of a comparably effective inducer for settlement and metamorphosis of larvae of the commercially valuable bivalves (oysters, mussels, scallops, etc.) is still under active investigation in our own laboratory and in other laboratories in the U.S. and abroad. Much work still remains to define the complex relationships between the inducing substances thus far identified (DOPA, DOPA analogs, and their conjugates in quinone-tanned proteins), and other unidentified factors which apparently control their activity and effectiveness.

As a potentially valuable spinoff from this research, we and our colleagues are learning how to control the settlement and metamorphosis of economically important damaging marine animals, including those which cause costly damage and fouling of boats, ships, immersed structures, and harbors.

Development of New Biochemical Induction Techniques of Even Lower Cost and Potentially Wider Applicability

In studies of the underlying biochemical and cellular mechanisms by which planktonic molluscan larvae detect stereochemically specific signal molecules required for induction of settlement and metamorphosis, and the mechanisms by which metamorphosis is begun, we have focused on the transducers of the GABA signal required by abalone larvae. In the experimentally tractable larvae of this species, we have found that induced transmembrane fluxes of specific ions function as early and essential transducers of the biochemical signal required for efficient settlement and metamorphosis. We have found that it is possible, in abalone larvae, to circumvent completely the use of the biochemical inducer normally required (i.e., GABA), and to induce completely successful settlement and metamorphosis simply by inducing a temporary specific ionic flux.

Previously we have shown that fluxes of calcium ion and cyclic AMP in larval tissues apparently mediate the induction of settlement and metamorphosis, and that artificially induced fluxes of calcium or cyclic AMP are sufficient to induce metamorphosis in the absence of GABA. In our most recent work, including experiments by one of our project trainees, Andrea Baloun, we have found that an earlier-acting, strong efflux of chloride ion appears to be one of the first direct mediators of the GABA signal in abalone larvae. (Apparently, GABA receptor-proteins control the activity of chloride-ion channels in the abalone larvae, just as they do in mammalian nerve cells.) Taking advantage of this recent observation, we have found that it is possible to induce completely successful settlement and metamorphosis of the abalone larvae, simply by inducing the temporary efflux of chloride ions from the larvae under carefully controlled conditions. This is easily and inexpensively done, simply by transferring the larvae from seawater to an inexpensive solution of defined ionic (salt) content for a given period of exposure, and then transferring the larvae back to normal seawater. The result is the fully dependable induction of completely successful settlement and metamorphosis (100%), with no mortality.

If similar induced ion fluxes (of chloride or other ions) normally mediate the action of the inducing signal in the control of metamorphosis in other shellfish as well, use of this simple technique may provide an inexpensive, simple, and effective means for inducing fully successful, physiologically normal settlement and metamorphosis in those valuable species for which other "recruiting" biochemical inducers of settlement and metamorphosis may not yet be fully identified. We will, therefore, test the applicability of this simple and inexpensive technique to other commercially valuable species.

Acceleration of Growth in Abalones

We recently discovered that two peptide hormones — insulin and growth hormone — can significantly accelerate the growth of abalones when these hormones are provided exogenously in very low concentration. Most significantly, we found, the extreme heterogeneity of sizes and growth rates generally observed in the cultivation of abalones (and other molluscs) is not the result of genetic variation, deficits in sperm or egg, or inadequate nutrition (as frequently cited in the semipopular aquaculture literature), but instead reflects physiological deficiencies in cultivation conditions which may be corrected or enhanced by external biochemical control. These results also indicate that genetic breeding programs based upon selection for apparently desirable growth rate properites (in abalones or other molluscs) cannot effectively be started until the physiological and biochemical requirements for optimal growth are fully defined. We are further investigating the mechanisms of regulation and acceleration of specific somatic protein and hormone synthesis and the regulation and acceleration of growth in abalones.

Synchronous Induction of Larval Settlement, Metamorphosis, and Rapid Postlarval Growth

In our continuing studies of the basic biochemical mechanisms underlying the control of molluscan development and growth, we have found that naturally occurring neurotransmitter-mimetic proteins are required for the induction of settlement, metamorphosis, and rapid postlarval growth in a number of valuable abalone and bivalve species. We have found that neurochemical transducers play a critical part in the induction and early control of these critical processes. Binding of naturally occurring neurotransmitter-mimetic inducing proteins to specialized chemosensory epithelial receptors on the larvae induces rapid transmembrane fluxes of ions, in turn resulting in the depolarization and firing of specific sensory neurons which activate development and growth.

On the basis of these findings, we are investigating the practicality and generality of an inexpensive new technique for the synchronous induction of larval settlement, metamorphosis, and rapid postlarval growth. In the case of abalones, GABA and GABA-mimetic proteins act to induce rapid efflux of chloride ions, just as GABA acts at the membranes of neuronal cells in other species. As the rapid efflux of chloride results in rapid depolarization of the chemosensory neuronal membrane, we were able to predict that a similar depolarization produced by artificial manipulation of the larval environment should similarly induce synchronous settlement, metamorphosis, and rapid postlarval growth. This prediction has been borne out in recent experimental results, in which we have found that simply by providing an excess of potassium ions (added as any of several inexpensive salts), we can most easily, reliably, and inexpensively trigger depolarization and resulting settlement, metamorphosis, and rapid growth.

We are presently testing the applicability of these basic new findings to other commercially valuable aquaculture species. The resulting new method offers the potential of being simpler, less expensive, and even more widely applicable than methods previously available. Results of these new findings will be published soon.

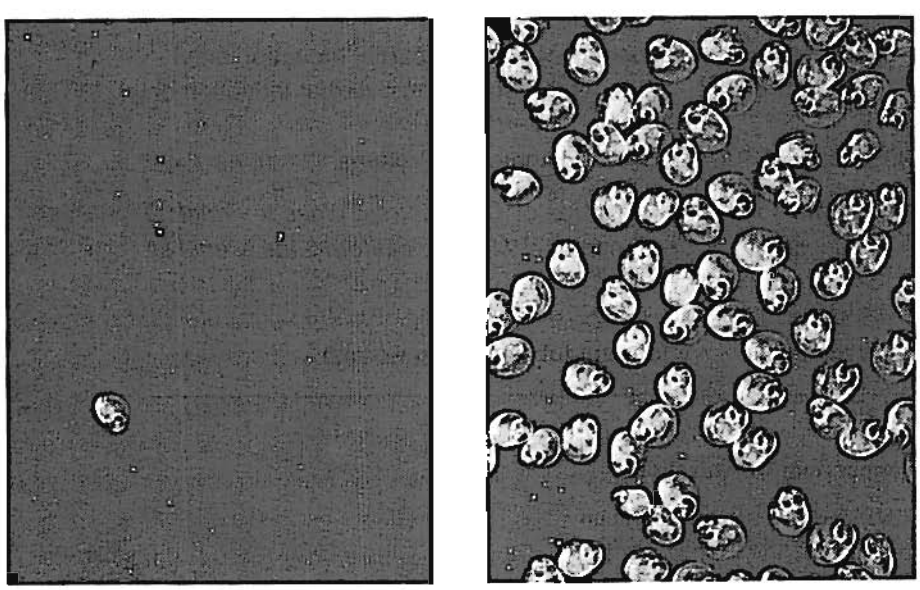


Figure 1. Results of Biochemical Engineering: new versus old technology. Seed abalone (*Haliotis rufescens*) 1 month old, produced using conventional hatchery technology (left), and new biochemical engineering technology with induction by GABA (right). These siblings were cultivated in parallel, with conventional feeding with diatoms and microalgae. Survival to 1 month with induction by GABA was 93%, without GABA, less than 1%. Average length of seed approximately 2 mm.

Table 1

Abalone Production Improved with Hydrogen Peroxide and GABA

Haliotis Species	Common Name	Industry Base
rufescens	Red abalone	USA
fulgens	Green abalone	USA, Mexico
corrugata	Pink abalone	USA, Mexico
cracherodii	Black abalone	USA, Mexico
kamtschatkana	Pinto abalone	USA, Canada
tuberculata	Ormer	Ireland, France, UK
midae	African abalone	Southern Africa
iris	Blue abalone	New Zealand
ruber	Black-lipped abalone	Australia

Table 2

Induction of Larval Settlement and Metamorphosis by Amino Acid-derived Neurotransmitters and Their Protein Conjugates

GABA and GABA Analogs Conjugated to Proteins	
Abalones	(9 species of *Haliotis*, & several hybrids)
Top shells	(2 species of *Trochus*)
Chiton	1 species of *Mopalia*)
Cone shell	(1 species of *Conus*)
Sea hares	(species of *Aplysia*; partial induction only)
Wood borers	(3 genera of shipworms; partial induction only)
DOPA and DOPA Analogs Conjugated to Proteins	
Oysters	(2 species of *Crassostrea*: *gigas* & *virginica*)
Mussels	(2 species if *Mytilus: californianus* & *edulis*)
Gregarious fouling organisms	(certain tube-building worms)

Cooperating Organizations
Ab Lab
Advanced Chemical Corporation
American Philosophical Society
Burroughs-Wellcome Foundation
California Abalone Association
California Department of Fish and Game
Commercial shellfish producers and brokers in California, Washington, Oregon, Delaware, Maryland, Virginia, Massachusetts, New York, and abroad
Delmarva Tri-State Development Agency
Dynasen Mariculture, Inc.
Galway Mariculture Laboratory, Ireland
Government and industrial aquaculture labs (CNEXO), France
Government and industrial labs, United Kingdom
Humboldt State University
Micronesian Mariculture Demonstration Project
National Institutes of Health
Santa Barbara Abalone Fishermen's Association
Southern California Coastal Water Research Project

Tasmanian Fisheries Development Authority, Australia
University of California
University of Delaware
University of Guam
University of Hawaii
University of Maryland
University of Washington
U.S. Navy Office of Naval Research
Washington Department of Fisheries
Woods Hole Oceanographic Institution

Publications

KITTING, C. K. AND MORSE, D. E. 1981. Newly metamorphosed *Haliotis* and *Crepidula* gastropod molluscs remove microscopic algae from encrusting coralline red algae. In *Symposium Proceedings, Western Society of Naturalists.* Santa Barbara. (Abstract).

MORSE, A. D. AND MORSE, D. E. 1982. Surface-associated molecules induce recruitment of molluscan grazers to *Lithothamnion.* In *Proceedings, First International Phycological Congress.* St. John's, Canada. (Abstract).

MORSE, D. E. 1980. Recent advances in biochemical control of reproduction, settling, metamorphosis and development of abalones and other molluscs: applicability for more efficient cultivation and reseeding. Proc. Natl. Shellfish Assoc. 70:132.

MORSE, D. E. 1981. Biochemical and genetic control of critical physiological processes in molluscan life-cycles: Basic mechanisms, water-quality requirements and sensitivities to pollutants; final report. In *University of California Sea Grant Program Biennial Report.* University of California, La Jolla.

MORSE, D. E. In press. 1981. Biochemical control of larval recruitment and marine fouling. In *Marine Biodeterioration.* U.S. Naval Institute, Bethesda.

MORSE, D. E. 1982. Molecular marine biology. In *Annual Report, Marine Science Institute.* University of California, Santa Barbara.

MORSE, D. E., DUNCAN, H., HOOKER, N., BALOUN, A., AND YOUNG, G. 1980. GABA induces behavioral and developmental metamorphosis in planktonic molluscan larvae. Federation Proceedings 39:3237-3241.

MORSE, D. E., HOOKER, N., AND DUNCAN, H. 1980. GABA induces metamorphosis in *Haliotis* V: stereochemical specificity. Brain Research Bulletin 5, Sup. 2:381-387.

MORSE, D. E., HOOKER, N., AND MORSE, A. D. 1981. Biochemical engineering for improved production of abalone and other valuable molluscs. In *Proc. Intl. Symp. World Mariculture Soc.* Venice. (Abstract).

MORSE, D. E., MORSE, A. D., AND HOOKER, N. 1981. Biochemical control of reproduction and larval recruitment in marine molluscs. In *Symposium Proceedings, International Society Invertebrate Reproduction.* Newcastle. (Abstract).

MORSE, D. E., TEGNER, M., DUNCAN, H., HOOKER, N., TREVELYAN, G., AND CAMERON, A. 1980. Induction of settling and metamorphosis of planktonic molluscan (*Haliotis*) larvae. III. Signaling by metabolites of intact algae is dependent on contact. In *Chemical Signaling in Vertebrate and Aquatic Animals,* D. Muller-Schwarze and R. M. Silverstein, eds. Plenum Publishing Corp., Plenum, N.Y.

MORSE, D. E. In press. Biochemical and genetic engineering for improved production of abalone and other valuable molluscs. In *Abstracts: Symposium on Recent Innovations in the Cultivation of Pacific Molluscs.* University of California Sea Grant Program, La Jolla, California. (Abstract).

MORSE, D. E. In press. Prospects for the California abalone resource: recent development of new technologies for aquaculture and cost-effective seeding for restoration and enhancement of commercial and recreational fisheries. In *Proceedings, Symposium on Coastal Resource Management.* California Coastal Commission, Monterey.

San Diego State University
R/A-44
1980-82

ARTIFICIAL CONTROL OF GAMETOGENESIS, SPAWNING, AND LARVAL PRODUCTION IN THE PURPLE-HINGE ROCK SCALLOP

David L. Leighton and Charles F. Phleger

Culture research on spawning and larval production of the purple-hinge rock scallop has traditionally been limited because gravid adults could only be obtained during peak periods of reproductive cycles in spring and fall (San Diego populations). The aquaculture industry, while most eager to embark upon rock scallop culture programs, has been reluctant to commence serious operations knowing spat availability would be sporadic. Our research has provided encouraging results suggesting adult broodstock may be conditioned to spawning readiness independent of season using relatively simple procedures and inexpensive foods.

Essential to this project is the newly renovated San Diego State University (SDSU) Aquaculture Research Laboratory at the Scripps Institution of Oceanography, La Jolla. Tanks, restructured floors and water tables, utility lines, and a seawater system supplying both filtered and unfiltered coastal water were completed in spring 1981. Ambient phytoplankton in unfiltered seawater is supporting optimal growth in juvenile scallops. A controlled photoperiod and water temperature system, tested initially at the SDSU Marine Laboratory in Mission Bay, has been in use in broodstock conditioning observations since midsummer 1981 at the Scripps Institution of Oceanography laboratory.

There are five principal findings and suggested conclusions from research in the first year of this project. 1) Gametogenesis in young adult broodstock rock scallops may be controlled through imposition of seasonal light and temperature regimes provided an adequate source of nutrition is provided. 2) *Tetraselmis suecica*, an alga easily and inexpensively cultured in our laboratory using liquid plant fertilizers, is sufficient nutritionally to support gametogenesis and gonadal growth. 3) Larvae produced by artificially conditioned broodstock are normal and viable. 4) A mixture of the Tahitian strain of *Isochrysis*, *Tetraselmis suecica*, and *Dunaliella salina* has proved to be a superior food for both larvae and juveniles. 5) Finely divided particulate matter is utilized as food by juvenile rock scallops.

These findings are supported by the following results. 1) Adult broodstock introduced to the experimental photoperiod and thermal regime (four situations: 8 hours of light, low (14-16°C) and high (18-22°C) temperatures, and 16 hours of light, low and high temperatures) in late July responded to ultraviolet (UV) stimulation in both September and October.

Rock scallops held experimentally for 3 to 6 months under several photoperiod and temperature regimes spawned with ultraviolet (UV) induction repeatedly at 1-month intervals. Groups of six individuals (6-8 cm shell diameter) occupied each situation, divided into two subgroups of three each. Spawning occurred among most individuals in the low-temperature groups and in half those in high-temperature, long-day situations when provided UV-irradiated seawater September 15 and October 12. A long day, low temperature regime (16-hour light, 14-18°C) was most effective in promotion of spawning readiness regardless of time of the year. 2) Daily feedings of 2-3 liters of concentrated cultures of *Tetraselmis* (~20,000 c/ml) to each subgroup (in 12 liters seawater) was sufficient to support gonadal growth. Somatic growth during the first two conditioning month-long periods has been negligible. *Tetraselmis* is cultured in clear acrylic 100-liter bowls ("cauldrons") using "Atlas" or "Ortho" fish emulsion liquid fertilizer at 10 ml stock/100 liters medium. 3) Larvae developing from eggs and sperm from conditioned adults appear in all respects to be normal. Survival in recent batches has been comparable to that for earlier spawnings of wild-nourished broodstock. During the last year (October 1981-October 1982), 18 separate spawnings have occurred in the SIO/SDSU Bivalve Culture Facility. Fifteen of these spawnings were induced with UV-irradiated seawater, the remaining three were spontaneous. The data shows a significant seasonal variation in larval vigor. Larvae produced between January 17 and April 5, 1982 showed greater growth and survival than those spawned before and after these dates. Greater numbers of deformed larvae were also associated with these outside dates. 4) A 1:1:1 mixture of Tahitian *Isochrysis*, *Tetraselmis suecica*, and *Dunaliella salina* supported an increase in mean shell diameter of 2.00 ±0.50 mm (SD) after 4 weeks when used as a diet for juvenile rock scallops (reported at the World Aquaculture Conference, Venice, Italy, September 1981). Significant growth also occurred in juveniles fed Tahitian *Isochrysis*, *T. suecica*, *Isochrysis galbana*, and *Rhodomonas* sp. as diet supplements. *Gymnodinium splendens*, *Monochrysis lutheri*, and *Dunaliella salina* alone were poor foods for juvenile rock scallops. 5) Finely divided particulate matter fed as radiolabeled abalone fecal matter was utilized as food by juveniles. That the particulate matter was incorporated into metabolic pathways is evident from the significant ^{14}C activity in biochemical fractions including DNA, RNA, lipid, protein, and carbohydrate. These data suggest that particulate artificial feeds might be added as diet supplements for early juveniles in a rock scallop hatchery.

Experiments were conducted to determine optimal concentrations that should be used during controlled fertilization to prevent polyspermy. Optimal concentrations for culture chambers containing approximately 30 eggs/ml was found to be 5 x 10^4 sperm cells/ml. Under controlled conditions, at these concentrations, 95% of the eggs developed normally yielding strong healthy larvae.

Late larval mortality has been attributed to heavy metal contaminants at detrimental levels in the ambient seawater. Experiments were designed to examine the effects of EDTA (a heavy metal chelator) on the growth of *Hinnites* larvae. Data shows that there was no significant positive effect on late larval mortality in the systems treated with the EDTA. It is unlikely that heavy metals are the detrimental factor causing the late larval mortality.

The use of antibiotics has been a standard procedure in rock scallop aquaculture. However, the effects of long- and short-term usage had not been investigated. A series of studies have demonstrated that only 4 days of antibiotic treatment are required following hatching, and that continued use for more than 10 days produced slower growth and a significant increase in mortality.

An innovative culture system utilizing a plunger mechanism to keep the larvae suspended with minimal agitation was used with developing *Hinnites* larvae. Each of three 175-liter containers had a large plunger that moved up and down at a rate of one cycle per minute. This was found to be sufficient to keep the larvae up in the water column. Preliminary results of two separate trials demonstrate the effectiveness of the system by producing larvae significantly larger and with less mortality than in the static control buckets. Continued work with this system is planned for the future.

This past year has produced much advancement in our hatchery methodology for the purple-hinge rock scallop. This last season has provided consistently excellent results with early and mid-life larvae. These encouraging results are somewhat dampened by the continual problems during the late larval period. Lethargic larvae sink to the bottom of the culture chambers, become rapidly contaminated with bacteria, and mortality soon results. We believe the problem lies in nutrition and culture methods which are now being improved.

Collection of early juveniles in the natural environment using collectors received renewed interest. Mesh bags (1 mm onion bags) packed with bundles of nylon monofilament line (gill net) were placed in mid-channel Mission Bay for a 1-year study of seasonal recruitment of settling larvae. The collectors were similar to those used to trap young stages of *Patinopecten yessoensis* in Japanese aquaculture, and of *Placopecten magellanicus* in Canadian aquaculture.

The time of settlement is important in planning spat collector placement for rock scallops. More spat appeared during spring and early summer than during the preceding winter and late summer at the same location in Mission Bay. Numbers of *Hinnites* spat per bag ranged between 14-43 during 3 months in spring (March 24-June 24, 1982) whereas numbers collected during the preceding winter ranged between 2 and 24.

The fact that spat collectors during spring and early summer also contained massive numbers of bay mussel (*Mytilus edulis*) spat (2000-20,000 per bag) indicates that the *Hinnites* spat population might have been much greater had there not been such competition for space. Winter bags had only a few hundred *Mytilus* spat per gill net collector.

Leaving spat collectors in the ocean for more than 4 months is not advisable. Factors important in *Hinnites* spat mortality after 4 months may include the following: 1) anoxia detected in spat collectors (held 5-6 months) by H_2S odor and black sediment, and 2) increase in crab or starfish predation (species of *Cancer, Pisaster*, and unknown crab species were numerous in these collectors). It must be noted that *Pecten* shells are thinner than *Hinnites* and therefore more susceptible to predation. In spat collectors held 3-4 months, all *Hinnites* were alive, yet there were many empty or fragmented *Pecten* shells.

Collectively, these new observations and findings concerning hatchery culture of the rock scallop should benefit the technology and should stimulate adoption of this shellfish by the aquaculture industry.

Cooperating Organizations

The Johnson Oyster Company

Publications

Cary, S. C., Leighton, D. L., and Phleger, C. F. 1981. Food and feeding strategies in culture of larval and early juvenile purple-hinge rock scallops, *Hinnites multirugosus* (Gale). J. World Mariculture Soc. 12:156-169.

Phleger, C. F., Leighton, D. L., and Cary, S. C. In press. 1981. Algae and detrital matter as food for juvenile purple-hinge rock scallops, *Hinnites multirugosus* (Gale). J. World Mariculture Soc.

Phleger, C. F., Leighton, D. L., and Cary, S. C. Recent advances in aquaculture of the purple-hinge rock scallop. Paper presented at the World Conference on Aquaculture, Venice, Italy. September 1981.

Phleger, C. F. and Rossi, S. S. December 1980. Dissolved organic carbon accumulation by juvenile rock scallops. Paper presented at the American Society of Zoologists meeting, Seattle, Washington.

Phleger, C. F. and Rossi, S. S. In press. Dissolved organic matter accumulation by juveniles of the purple-hinge rock scallop, *Hinites multirugosus* Gale. In *Comparative Biochemistry and Physiology.*

University of California, Davis
R/A-45
1981-82

Douglas E. Conklin and Wallis H. Clark

During this past year we have focused our multidisciplinary research efforts on significant problem areas that restrict the culture and domestication of aquatic animals important to California aquaculture and fisheries interests. Lobsters of the genus *Homarus*, sturgeon of the genus *Acipenser*, and oysters of the genus *Crassostrea* are the three principal animals used in our research. Although the particular complex of biological questions that need to be answered varies for each species, the basic problems can be grouped into two main topics: 1) control of the reproductive cycle and the development of reliable stocks and 2) the optimization of husbandry for maximum productivity. In resolving the biological problems within these two main areas we employed the special expertise of the various principal investigators associated with the project within the fields of reproductive biology, genetics, endocrinology, physiology, nutrition, and pathology. Some of the major accomplishments of these investigators are summarized in this report.

Control of the Reproductive Cycle in Homarid Lobsters

Current concepts of intensive farming of the lobster *Homarus americanus* imply year-round harvesting, thus the year-round availability of seed larvae for continuous stocking. Significant progress in the development of techniques for controlling spawning and larval production in lobsters has been achieved at Bodega Marine Laboratory (BML). In particular, the demonstration that a change in photoperiod from short to long days triggers final vitellogenesis has allowed unprecedented insight into how environmental factors such as temperature and photoperiod affect the complex and largely antagonistic interactions between growth and reproductive processes in a decapod crustacean (see figure 1).

This basic research has allowed Dr. Hedgecock to develop an operational hypothesis for the management of lobster broodstock. The chief requirements of a broodstock husbandry scheme are as follows: 1) control over molting and vitellogenesis; 2) avoidance of conflict between the antagonistic processes of growth and reproduction; 3) elimination of alternating barren and fertile molt cycles; and 4) production of eggs in virtually all months of the year. We hypothesize that these goals may be achieved by manipulating temperature and photoperiod such that a complete ovarian cycle, including brooding and hatching, is contained within each molt cycle (see figure 2).

During the past year various aspects of this husbandry plan have been tested. First, an experiment was made to see if 3 months of short days were as effective as 4 months in setting the stage for long-day induction of vitellogenesis. Although the percentages of extrusions in the 3- and 4-month treatments, 13 and 33% respectively, suggested that 3 months might be insufficient, the overall low rate of extrusion led us to question the suitability of our deep-tank experimental broodstock system. At the same time we began cycling BML broodstock through a short-day room where the animals are simply maintained for 4 months in our usual racked-trough systems before moving to similar systems under long-day conditions. The extrusion rate of these females has been high overall (~60%), but varies depending on how soon after molting the female is transferred to short days to initiate the husbandry cycle (figure 2). A lower rate of extrusion (only 27%) by females not placed under short days within 3 weeks of molting probably results from subsequent interference of long-day-induced vitellogenesis by the upcoming molt. Modifications of the husbandry system that would have molting occur during the short-day period or within a 120-day "safe window" after long-day onset are being tested. Reduction of the short-day period below 4 months is also being reexamined as this might allow the original husbandry cycle to be effective when the molt cycle is less than 12 months in duration.

Successful induction of egg laying by lobsters has uncovered a problem with egg loss. Only about half of the females that successfully lay eggs in the laboratory carry their eggs until hatching, and in many of these cases, clutch size is reduced to a few hundred eggs. As egg loss represents the most immediate constraint upon commercial development of lobster farming, this problem became the focus of a related Sea Grant project (R/NP-1-11G) that brought together Dr. D. Hedgecock, Dr. P. Talbot of UCR, and Mr. P. Wilson of Aquaculture Enterprises to investigate several possible causes of egg loss. Progress on solving this problem is detailed in the annual report for that project.

Using the operational broodstock husbandry plan and conservative estimates of the rates of successful mating, spawning, brooding, hatching, and larval and juvenile survival, the number of broodstock needed for a commercial lobster farm is calculated to be about 1,000 reproductive females. This is only about five times as large as the existing BML research broodstock and the likelihood of further improvements in broodstock efficiency, such as a reduction in egg loss, appears to bring the goal of year-round mass production of larval lobsters well within reach.

The Reproductive Cycle in Other Crustaceans and Molluscs

Aspects of reproduction in crustaceans are also being examined in the rock prawn, *Sicyonia ingentis* through a collaborative effort between Dr. Chang's and Dr. Clark's research groups. Correlations have been observed between the molting and reproductive cycles during the year. They have also characterized the yolk protein and developed methods for analyzing ovarian development.

Recent studies under the direction of Dr. Chang have examined techniques for the successful spawning of the potentially important native mollusc, *Mytilus californianus*. It was found that scraping of the shells in combination with hydrogen peroxide treatment was the most successful. Various feeding and temperature regimes have been tested to determine the optimal conditions for larval development. Observations have also been made on the physical and chemical factors necessary for larval settlement in this mollusc.

Endocrine Control of Growth in Crustaceans

The chemical identity of the lobster molting hormone has been determined to be 20-hydroxyecdysone. By means of a radioimmunoassay, the levels of this molting hormone have been determined by Dr. Chang's group in normal and eyestalk-ablated animals. The levels of the hormone may serve as a useful means of determining the molt stage. Progress has been made in the elucidation of the control of the concentration of the molting hormone. It appears that there is a hormone secreted by the X-organ sinus gland complex of the eyestalk. Both a biological and a chemical assay for the isolation of this factor have been developed. Dr. Chang is in the process of collecting sufficient glands to carry out further chemical characterizations.

Development of larvae of lobsters and other crustaceans also appears to be regulated by the molting hormone. We have observed that the addition of exogenous arthropod growth regulators, including 20-hydroxyecdysone, create developmental abnormalities.

Formulated Rations for Lobster Aquaculture

Juvenile lobsters fed exclusively on artificial diets have continued to grow successfully for the last 3.5 years. Females cultured on these diets have reached reproductive maturity and some have already been mated with males that are part of our laboratory holdings. Within the next year we will be able to determine how adequate these artificial diets are for normal vitellogenesis, fertility, and fecundity.

Our work investigating sterol requirements and metabolism in the lobster continues. We have followed cholesterol titers in the serum throughout the molt cycle and have observed reduced levels throughout the molt cycle when phosphatidylcholine is absent from the diet. In association with Dr. Chang, Dr. Conklin's group has used a radioimmunoassay technique to quantify ecdysteroid (crustacean hormones derived from cholesterol) levels in the serum. The absence of phosphatidylcholine in the diet apparently exerts no effect on ecdysteroid titers throughout the molt cycle. After two experiments there is strong evidence indicating that juvenile lobsters have no requirement for vitamin D_3 (cholecalciferol). Growth and survival were not significantly different among lobsters fed artificial diets containing D_3 concentrations of 0, 500, 5,000, and 50,000 IU/100 gm of diet. We have attempted to completely substitute cholesterol in our purified diet with less expensive plant-derived sterols called phytosterols. Complete substitution has been unsuccessful; growth rates and survival are significantly reduced. However, there is some indication that dietary phytosterols may exert a cholesterol-sparing effect.

In our continuing attempt to understand the lobster's critical requirement of phosphatidylcholine in our purified diet, we are currently analyzing a possible sparing effect as it relates to the addition of crustacean-derived protein to the diet.

Our work with the role of dietary lipids has recently involved carotenoids. Dr. D'Abramo has evaluated the effectiveness of various pure carotenoids and crude sources of these compounds in producing pigmentation in the lobster. Results have permitted us to suggest possible biosynthetic pathways involving the oxidation and hydroxylation of these compounds (see figure 3). Proximity of the carotenoids to astaxanthin (the red pigment characteristic of cooked lobsters) in the biosynthetic scheme and provision of the pigment dissolved in a triglyceride source appear to be two important factors contributing to effectiveness.

The leaching of water-soluble nutrients and a possible requirement of vitamin C (ascorbic acid) are being studied concurrently. Because of its high solubility, proper dietary provision of vitamin C will be critical if there is a requirement in lobsters. Initial analytical investigations of the ascorbic acid content of lobster tissue provided equivocal results. An experiment is currently being conducted which should partially assist in our understanding of a possible ascorbic acid requirement as well as the significance of leaching.

Using a prototypical metabolism chamber we have begun analyses of the utilization of macronutrients in artificial diets fed to juvenile lobsters. In the two diets studied, protein and lipid digestion was >90%. Carbohydrates, represented as nitrogen-free extract and primarily in the form of corn starch, were only 65% digested. Further protein, lipid, and carbohydrate digestibility studies are planned.

Disease Diagnosis for California Aquaculture Industries

The pathology laboratory under the direction of Dr. Hedrick continues to provide diagnostic services for California aquaculturists at no cost. These services are also available and utilized by research groups at the BML when disease problems are encountered. The capabilities of the laboratory to detect viral diseases among cultured finfish has been greatly expanded to a total of 20 continuously cultured cell lines from assorted species.

The water quality laboratory continues to serve all research groups by monitoring the water for both chemicals and bacteria detrimental to experimental animals.

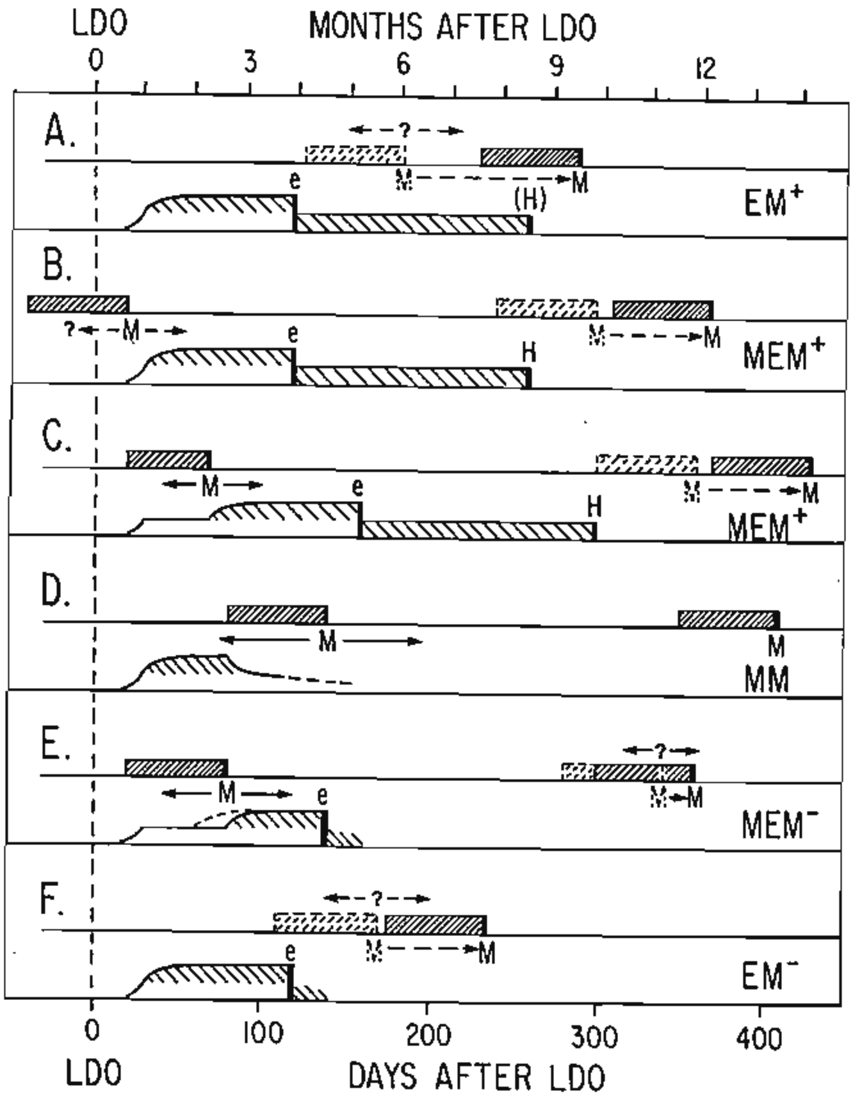


Figure 1. Representative relationships between extrusion and molting in laboratory-held female lobsters. "LDO" is long day onset. "Active premolt" terminating in ecdysis is represented by finely hatched block ending with a heavy vertical line at M. Range of observed LDO-molt intervals are given by double-headed arrows about M (with question marks where it is uncertain). Presumably delayed premolt periods and molts are indicated by broken lines and single-headed arrows. Periods of oocyte and zygote development are represented by coarse hatches with heavy vertical lines at e and H indicating extrusions and hatches, respectively. Cases A through C represent successful reproduction by females that A) postpone molting until after hatching (EM+); B) molt soon enough (i.e. less than 45 days) after LDO to cause no delay in vitellogenesis (MEM+); or c) molt between 45 and 120 days post-LDO with a compensatory delay in egg extrusion (MEM+) in all cases, brooding of eggs and perhaps vitellogenesis itself apparently delays molting. Cases D through F show possible scenarios for conflict between molting and reproduction; D) molting outside of the 120-day window is rarely followed by extrusion (MEM-); E) egg loss from females that extrude shortly after molting may indicate an effect of molting upon normal egg development; and F) egg loss from females that molt shortly after extrusion may indicate a failure of the molt inhibition usually associated with vitellogenesis (from Nelson *et al.*, submitted).

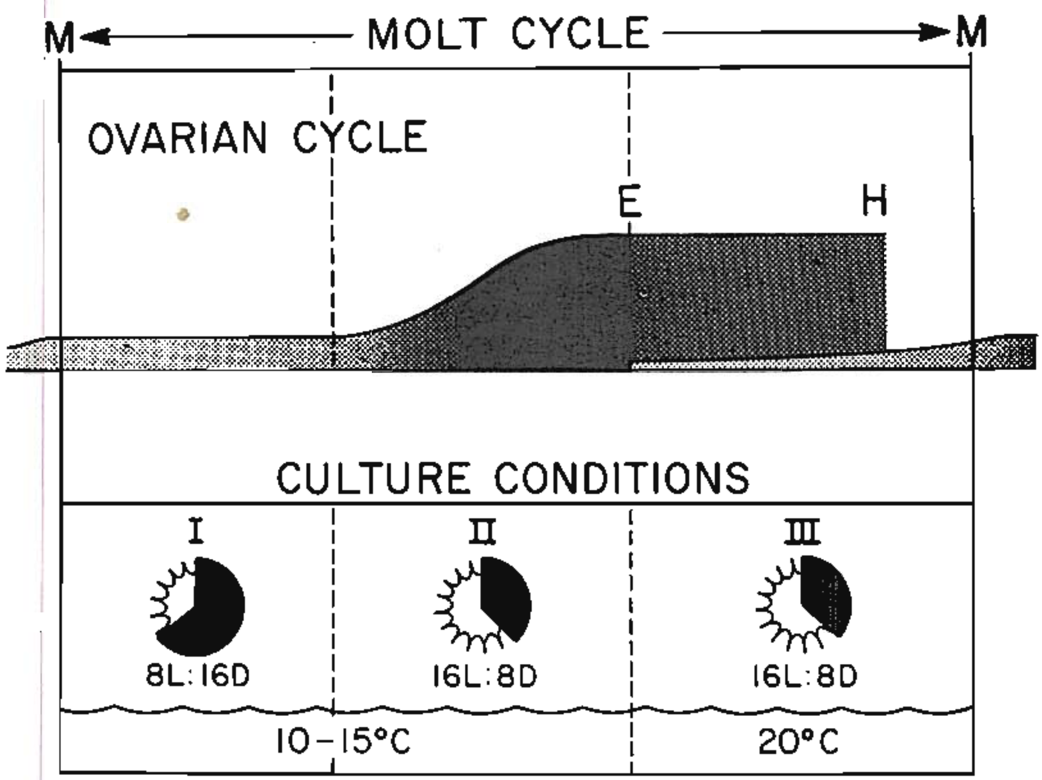


Figure 2. This represents a working hypothesis for successful management of *Homarus* broodstock. Cycling of female lobsters through three holding systems with indicated temperatures and photoperiods should result in egg extrusion and hatching within each intermolt interval. Scheduling of hatching in all months would be achieved by developing (through temperature manipulation) cohorts of broodstock molting in each month of the year (from Hedgecock, 1982).

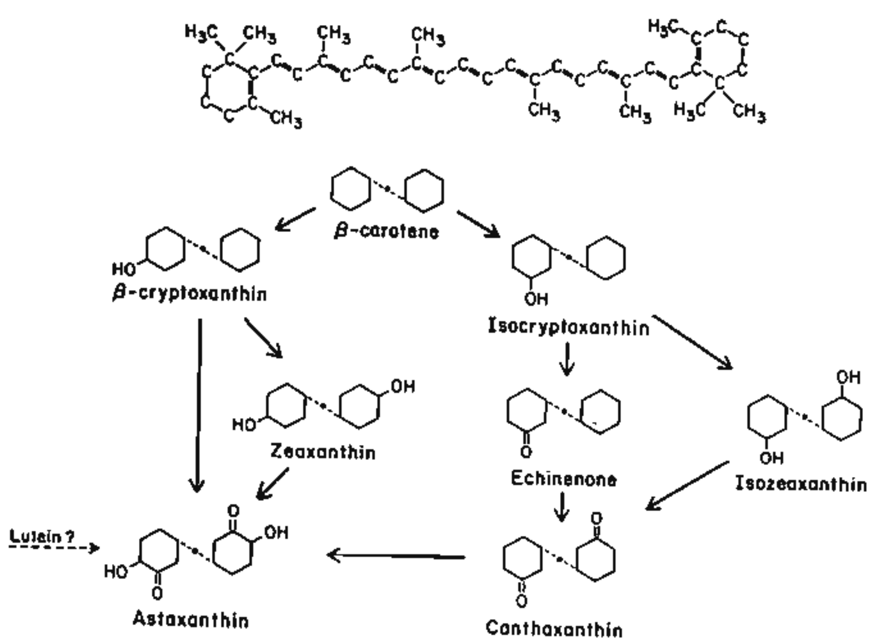


Figure 3. Probable biosynthetic pathways used by lobsters to produce astaxanthin, the primary pigment of the carapace. Not all intermediaries in the various schemes are presented (from D'Abramo *et al.*, submitted).

Cooperating Organizations
California Department of Fish and Game
Henkel Corporation, Minneapolis
Idaho Department of Fish and Game
Louisiana State University
Malaspina Junior College and Pacific Biological, Nanaimo, B.C.
Oregon Department of Fish and Wildlife
United States Department of Commerce
United States Department of Interior
University of California, Los Angeles
Wisconsin Department of Natural Resources

Publications

CHANG, E. S. In press. 1982. Analysis of insect hormones by means of a radial compression separation system. J. Liquid Chromatography.

CHANG, E. S. AND CONKLIN, D. E. In press. 1983. Hatchery - lobster. In *Mariculture*, J. P. McVey, ed. CRC Press, Inc., Boca Raton, FL.

CHANG, E. S. AND O'CONNOR, J. D. In press. Observations on the metabolism and transport of carbohydrates and lipids of crustaceans. In *Biology of the Crustacea*, D. Bliss and L. Mantel, eds. Academic Press, New York.

CONKLIN, D. E., BORDNER, C. E., GARRETT, R. E., AND COFFELT, R. J. In press. Improved facilities for experimental culture of lobsters. In *Proc. World Maric. Soc.*

CONKLIN, D. E. AND CHANG, E. S. In press. 1983. Growout - lobster. In *Mariculture*, J. P. VcVey, ed. CRC Press, Inc., Boca Raton, FL.

CONKLIN, D. E., D'ABRAMO, L. R., AND NORMAN-BOUDREAU, K. A. In press. 1983. Nutrition - lobsters. In *Mariculture*, J. P. VCVey, ed. CRC Press, Inc., Boca Raton, FL.

CONKLIN, D. E. In press. Exoskeleton biosynthesis/crustacea. In *Proc., Second international conference on aquaculture nutrition: biochemical and physiological approaches to shellfish nutrition*, G. D. Pruder, C. J. Langdon and D. E. Conklin, eds. LSU Press.

D'ABRAMO, L. R. AND BAUM, N. A. In press. Choline requirement for the microcrustacean, *Moina macrocopa*: a purified diet for continuous culture. Biol. Bull.

D'ABRAMO, L. R., BORDNER, C. E., CONKLIN, D. E., BAUM, N. A., AND NORMAN-BOUDREAU, K. A. 1981. Successful artificial diets for the culture of juvenile lobsters. J. World Maric. Soc 12(1):325-332.

D'ABRAMO, L. R., BORDNER, C. E., AND CONKLIN, D. E. 1982. Relationship between dietary-phosphatidylcholine and serum cholesterol in the lobster *homarus* sp. Marine Biology 67:231-235.

HEDGECOCK, D. In press. 1982. Maturation and spawning - lobster. In *Mariculture*, J. P. McVey, ed. CRC Press, Inc., Boca Raton, FL.

DEVELOPMENT OF PROCEDURES FOR ARTIFICIAL INSEMINATION AND SPERM STORAGE IN LOBSTERS

University of California, Riverside
R/A-46
1981-82

Prudence Talbot

Our work during the past 12 months has been focused on the following three projects to begin 1) long-term storage of lobster sperm, 2) artificial insemination of freshly molted female lobsters, and 3) analysis of the mechanism of sperm storage in naturally mated female lobsters. Each of these areas will be considered separately.

Long-term Storage of Lobster Sperm

Our long-range goal is to bank lobster sperm for subsequent use in artificial insemination. Our initial attempts at freezing lobster sperm were completely unsuccessful; freezing or thawing killed all sperm cells. We have modified our storage technique to resemble that used by the female. Entire spermatophores (sperm plus coating materials) are submerged in mineral oil and stored in sterile tubes at 4°C. This past year we have collected numerous spermatophores from males at Market Basket (UCR samples). I also traveled to Aquaculture Enterprises and Bodega Marine Laboratory to introduce the collection technique in these laboratories. We have obtained additional spermatophore samples from these sources. The spermatophores are sampled periodically to evaluate sperm viability. We have recovered viable sperm from spermatophores stored as long as 8 months.

As an important extension of this project, we sampled all the males at Aquaculture Enterprises, Oxnard and Bodega Marine Laboratory for spermatophore production (Cathy Thaler later made equivalent assessments at the Monterey laboratory). We learned that laboratory-maintained males usually produce spermatophores of excellent quality. Those males that did not were identified and can be excluded from subsequent matings. We were disappointed to learn that unequivocal hybrid males [*H. gammarus* (female) and *H. americanus* (male)] produced the spermatophore wall but no sperm. This knowledge is important as it indicates these males should not be used in matings.

Artificial Insemination of Freshly Molted Female Lobsters

Our data are preliminary but very encouraging. In April, I traveled to Aquaculture Enterprises, Oxnard to teach Phil Wilson and Cathy Thaler how to artificially inseminate lobsters. We performed several inseminations that day. Since then, Cathy Thaler has been artificially inseminating all the freshly molted females at the Monterey Laboratory. To date, five of these females have extruded eggs. In two cases, the egg samples were taken close to spawning and cleavage could not be evaluated. These females lost their clutches before more samples could be taken. The other three artificially inseminated females had unequivocally cleavaged eggs. The cleavage patterns were normal indicating fertilization had probably taken place. We are especially encouraged by these preliminary data on lobster artificial insemination and will continue monitoring these females in collaboration with Cathy Thaler.

Analysis of the Mechanism of Sperm Storage in Naturally Mated Female Lobsters.

Through the efforts of Will Borgeson and Linda Sautter (Bodega Marine Laboratory) and Phil Wilson and Cathy Thaler (Aquaculture Enterprises) we have obtained, fixed, and stored over 50 annuli (female receptacle for sperm). We have not yet had time to analyze these, but plan to do so during the coming year. Our analyses will provide background data on the sperm storage mechanism used by the female. This knowledge will be valuable in subsequent assessments of how the female treats the artificially inseminated spermatophores.

Table 1

Mean Length (mm) of Spermatophores Collected from *H. americanus* at Bodega Marine Laboratory

Date	Spermatophore Length (mm) ± S.E.	N#
3-18-82	9.1 ± 2.0	20
6-10-82	16.7 ± 2.0	16
6-26-82	23.2 ± 3.1	13
7-14-82	17.6 ± 3.1	13
7-28-82	15.4 ± 4.9	11
9-16-82	18.9 ± 3.1	13
10-26-82	13.5 ± 2.4	13

N# = number of males

Table 2

Mean Length of Spermatophores Reported for Individual Males

Male	N#	Spermatophore Length (mm) ± S.E.
1	6	22.3 ± 5.9
5	7	16.0 ± 2.5
6	6	19.0 ± 6.1
7	6	21.3 ± 6.3
9	6	16.2 ± 8.7
11	7	26.1 ± 3.8
12	7	13.9 ± 4.3
13	7	11.7 ± 3.4
14	6	11.1 ± 3.4
15	6	21.5 ± 2.7
16	7	23.0 ± 2.2
17	5	19.6 ± 5.1
18	6	13.8 ± 4.7
19	7	5.9 ± 3.6
20	6	8.7 ± 2.7

N# — number of trials

Cooperating Organizations
Aquaculture Enterprises, Monterey and Oxnard
Bodega Marine Laboratory

Publications

DUDENHAUSEN, E. AND TALBOT, P. 1982. An ultrastructural analysis of mature sperm from crayfish *Pacifastacus leniusculus* Dana. Int. J. Invert. Reprod. 5:149-159.

KOODA-CISCO, M. AND TALBOT, P. 1982. A structural analysis of the freshly extruded spermatophore from the lobster, *Homarus americanus*. J. Morph. 172:193-207.

VARIATION IN INTRACELLULAR PH AND ITS EFFECT ON HATCHABILITY OF CYSTS OF THE BRINE SHRIMP *ARTEMIA SALINA*

University of California, Davis
R/A-47
1981-82

John H. Crowe

Despite the commercial significance of the *Artemia* cyst in aquaculture, our understanding of the biochemical and physiological events involved in the development and hatching of these cysts is rudimentary, because of the refractory nature of this living material. *Artemia* hatching failures are a common and costly problem for aquaculturists, suggesting the importance of basic research into the mechanisms regulating the transition from dormancy to development. By applying the new technique of *in vivo* nuclear magnetic resonance spectroscopy we have gained the first glimpse into the intracellular ionic milieu of the embryo, and have shown that large intracellular pH changes (in fact, the largest ever reported) accompany the activation of metabolism and development; in contrast, no such pH_i changes occur in nonhatching cysts. Treatments which block the natural pH_i change also block the initiation of metabolism and development in a reversible fashion.

Goals

Our direct goals during the first 12 months of this grant have been 1) to confirm and amplify our initial observations of intracellular pH (pH_i) changes accompanying the transition between dormancy and development in hydrated *Artemia* cysts and 2) to achieve an assessment of the physiological significance of pH_i in the maintenance and termination of dormancy in these cysts.

Summary of Progress

Using the noninvasive technique of *in vivo* ^{31}P nuclear magnetic resonance spectroscopy (NMR) we have recently documented that encysted embryos of the brine shrimp *Artemia salina* undergo pronounced pH_i changes during transitions between anaerobic dormancy and aerobic development initiated by transfer between nominally O_2-free and O_2-saturated buffers (Busa *et al.*, 1982). Anaerobic dormant cysts display an acidic pH_i of 6.3, which increases during the first 4 hours of aerobic incubation to a maximum of $\geqslant 7.9$ (the upper limit of detection with this technique). Similarly, when early aerobic development is interrupted by an interval of anoxia (during which the embryos re-enter dormancy) pH_i decreases from $\geqslant 7.9$ to 6.8 during the first hour and continues to decrease, more slowly, to 6.3 during extended anoxia. We have also shown that the pH_i of dormant cysts is independent of external pH (pH_o), probably due to the general impermeability of the cyst shell to ions. In light of the pronounced sensitivity of most biochemical reactions to pH, we have hypothesized that these pH_i changes may be fundamental in regulating the metabolic transition between dormancy and development, as has recently been demonstrated for the pH_i change accompanying sea urchin egg activation. Recent demonstrations by other workers that similar large pH_i changes accompany the germination of yeast and bacterial spores (see Busa 1982a,b for reviews) make this hypothesis even more attractive.

Our second goal — to demonstrate the physiolological significance of these pH_i changes — has proven quite technically challenging; nevertheless, we have achieved considerable progress. Our rationale has been to manipulate pH_i experimentally using weak acids and bases which are able to penetrate the cyst shell; to monitor with the NMR spectrometer the pH_i changes achieved; and to determine the effects of such treatments on hatching, respiration, and carbohydrate metabolism.

CO_2 readily penetrates the cyst shell, enters the cells, and acidifies pH_i by hydrating to form H_2CO_3, which rapidly dissociates into HCO_3^- and H^+. By superfusing cysts within the NMR spectrometer with oxygen-containing buffers equilibrated with various partial pressures of CO_2, we have recently achieved depressions of pH_i (below its normal aerobic value of $\geqslant 7.9$) to 7.4 under 7% CO_2 and to <6.8 under 60% CO_2 (40% O_2) (Busa and Crowe, 1983). Using flow-through Clark-type O_2 electrodes, we have simultaneously observed that respiration is strongly inhibited at the low pH_i typical of dormant cysts; under 60% CO_2 (pH_i 6.8) respiration is inhibited by about 66%. It seems quite likely that the low residual respiration under these conditions is due to the ability of membrane-permeable weak acids such as CO_2 to uncouple oxidative phosphorylation.

The inhibition of respiration at low pH_i is paralleled by a dramatic inhibition of development. Cysts incubated under 40% O_2/60% CO_2 do not hatch for at least 110 hours (controls commence hatching at about 12 hours and are finished by 72 hours). Hatching proceeds normally upon removal of CO_2. Thus, as judged by both developmental and physiological criteria, the low pH_i typical of dormant cysts appears to be directly involved in the establishment of dormancy. Obviously, it would be desirable to reproduce these results using some other weak acid to depress pH_i (to rule out non-pH-related effects of CO_2), and we are at present surveying other acids for their ability to cross the cyst shell.

In keeping with our ultimate goal of improving the hatchability of *Artemia* cysts used in aquaculture, we have very recently initiated studies involving experimental *elevation* of pH_i using the weak, permeable base NH_3. The observation that ammonia activates sea urchin egg development dates back to the turn of the century, and this effect has recently been shown to be due to the ability of ammonia to elevate pH_i. To the extent that hatching failure in *Artemia* involves a failure to alkalinize pH_i, ammonia treatment might be expected to improve hatchability by activating otherwise viable cysts. As these efforts are still in their initial stages we have no results to report at present. However, in view of the dramatic effects of CO_2 on depressing pH_i and cyst metabolism, we believe we have good reason to suspect that permeant gases such as NH_3 will have the opposite effects. We intend to test that hypothesis in the next year.

Application of Project Results

We have recently shared our experience in *in vivo* spectroscopy and superfusion of these cysts with Dr. Patricia Seitz (of Dr. Carlton Hazelwood's lab at Baylor College of Medicine), who is now applying these techniques to study the hydration-dependence of cyst metabolism. We feel it is likely that these techniques will see wider application in the near future, yielding important insights into *Artemia* cyst metabolism. Such insights will almost certainly lead to applications of importance to aquaculture, *i.e.*, improvement of hatchability by artificially manipulating pH_i.

Cooperating Organizations

University of California, Davis Aquaculture program

References

BUSA, W. B. 1982a. Cellular dormancy and the scope of pH_i-mediated metabolic regulation. In *Intracellular pH*, R. Nuccitelli and D. W. Deamer, eds. Liss, New York.

BUSA, W. B. 1982b. Regulation of cellular metabolism by alterations in intracellular pH. Am. J. Physiol. (invited review).

BUSA, W. B. 1982c. pH_i mediates the dormancy/development transition in *Artemia* embryos. Presented at the 1982 West Coast Regional Developmental Biology Conference, Fallen Leaf Lake, California.

BUSA, W. B. AND CROWE, J. H. 1983. CO_2 treatment mimicks dormancy in aerobic *Artemia* embryos. Nature. (submitted)

BUSA, W. B., CROWE, J. H., AND MATSON, G. B. 1982. Intracellular pH and the metabolic status of dormant and developing *Artemia* embryos. Arch. Biochem. Biophys. 216(2):711-718.

CULTURE OF MARINE BIVALVES; NUTRITIONAL ROLE OF DISSOLVED ORGANIC SOLUTES

University of California, Irvine
R/A-48
1981-82

Grover C. Stephens

The basic goal of this project is to assess the role of naturally occurring organic solutes in the nutrition of marine bivalves. Related goals directly relevant to mollusc mariculture are 1) the investigation of the feasibility of supplementing particulate diets in mariculture to improve product survival and quality and 2) the investigation of natural resources to permit precise estimates of water quality in mariculture.

Two recent advances permit an effective attack on these goals. First, the use of high performance liquid chromatography (HPLC) allows precise measurement of organic solutes at the extremely low concentrations which are typically found in natural waters. Second, bacteria-free experimental material can now be produced in the laboratory which permits an additional goal to be added: precise description of nutritional requirements of bivalve larvae.

In the past year, we have refined HPLC techniques significantly. We have demonstrated net entry of naturally occurring free amino acids in both larval and adult marine bivalves. We have shown that free amino acid concentrations are profoundly modified by typical procedures employed in commercial mariculture operations. These modifications are produced by filtration and by inadvertent addition of major amounts of dissolved organic solutes as contaminants in particulate food. Finally, we are currently investigating quite remarkable microvariations in the availability of dissolved resources in the inshore habitat.

Cooperating Organizations
Bodega Marine Laboratory (UC)
University of California, Irvine

Publications

MANAHAN, D. T., DAVIS, J. P., AND STEPHENS, G. C. In press. Bacteria-free sea urchin larvae take up neutral amino acids selectively from seawater. Science.

MANAHAN, D. T. AND STEPHENS, G. C. In press. The use of high performance liquid chromatography to measure dissolved organic compounds in bivalve aquaculture systems. Aquaculture.

STEPHENS, G. C. In press. Dissolved organic material and the nutrition of marine bivalves. In *Proceedings of the Second International Conference on Nutrition in Aquaculture* . World Mariculture Society. Delaware, November 1981.

PHYSIOLOGICAL ASPECTS OF *PORPHYRA PERFORATA* MARICULTURE: THE EFFECT OF DESICCATION ON PHOTOSYNTHESIS AND ON THE CONTROL OF EPIPHYTES

Stanford University
R/A-49
1981-82

Isabella A. Abbott

The work being reported here represents a mariculture test of physiological hypotheses derived from dissertation research by Sea Grant trainee, Celia M. Smith. This dissertation research probes photosynthesis adaptations among intertidal algae which allow species-specific tolerance to environmental stresses. Algal ability to grow under intertidal conditions is linked with their photosynthetic tolerance to intertidal stress. Many of these intertidal algae are commercially significant species such as agarophyte *Gelidium coulteri* and carrageenophyte *Rhodoglossum affine* and are representative of the edible genus *Porphyra*, *P. perforata*, and *P. nereocystis*.

Algal mariculture studies, such as Sea Grant project R/A-34, document increases in intertidal algal growth when these species are placed in continual submergence culture rather than daily exposures typical of field conditions. But, continual submergence in tank culture has an adverse side effect of allowing epiphyte growth beyond levels observed in field conditions.

Epiphytes present a serious fouling problem causing decreased production and quality of commercially grown and harvested algae. Some epiphyte species can cause diseases as well. Japanese investigators have demonstrated akagusare, the red wasting disease of *Porphyra* field culture, is the result of a fungal infection which can cause crop failure in only 2-3 weeks. Despite the economic impact that epiphytes can have on crop value, little is known of their species identity or physiological tolerances to field or tank conditions.

It is apparent that intertidal plants tolerate the stresses of intertidal exposure well enough to exist in that zone. Epiphytes are not found as abundantly as macroalgae in intertidal areas. Because of reduced exposure time, continual submergence culture alters environmental conditions and could actually favor small, quickly dividing epiphyte species over more slowly growing macroalgae. This would explain dramatic epiphyte increases observed in tank culture.

We originally proposed that epiphyte species possess reduced physiological tolerances to exposure, in contrast to those of intertidal macroalgae, and that this reduced tolerance may be important in determining epiphyte distributions. It this is so, then exposure conditions could be applied to culture conditions which would slow epiphyte growth but do not impair more tolerant macroalgal growth. This type of epiphyte control for tank or and field culture has the potential to be a cost-effective way to enhance quantity and quality of macroalgal cultures, with a minimum of handling. Exposure tolerance by epiphytes and macroalgae can be tested in two ways: 1) studying photosynthetic tolerances to exposure and 2) documenting growth as a function of exposure levels.

Three goals were established for this study: 1) to determine what the impact of exposure is on intertidal macroalgal growth in tank or field culture, 2) to discover what the effect of exposure is on photosynthesis for macroalgae and epiphytes, and 3) to examine what the impact of exposure is on epiphyte growth and distribution.

A powerful tool used in these studies is the ability to concurrently assay photosynthesis and plant growth. With this comparative approach, we are able to diagnose whether poor plant growth is caused by harsh seasonal conditions or poor photosynthetic performance. This type of information should be the basis for efficient strain selection as well as effective resource management.

Results

1. Growth rates for *Porphyra perforata* were calculated as changes in fresh weight, as well as length of plants, for all experiments. Dual monitoring of growth in this fashion eliminates bias of solely measuring weight changes, which may be caused by epiphyte additions to plant weight. Measure of plant length against their weight was statistically tested (figure 1) and shown to be remarkably linear for substantial sample size ($n = 61$, $df = 59$, $R^2 = 0.516$, $p < .001$, with Y gm fresh weight = 0.064 cm length + 0.136).

To study the effect of air drying on short-term growth, tank culture experiments exposed 272 plants to air from 0 to 12 hours a day. Figure 2 demonstrates a linear trend established by these experiments; growth of plants is directly proportional to amount of time spent exposed to air-drying conditions: $R^2 = 0.983$, $p < .005$, Y growth rate = - 0.622 X hours exposure + 8.776 based on weight changes. This decrease in production was observed both for changes in length (figure 2A) and weight (figure 2B).

Short-term exposure of 2 hours shows no statistical distinction in length or weight measurements from continually submerged plants (figure 2). However, plants desiccated for 2 hours a day sustained stable growth at <6% a day for over 3 weeks, twice the time continually submerged plants were observed to sustain growth. In summary, continually submerged plants were able to maintain high growth rates but only for short periods. Even if mild desiccation slightly slowed growth, it had the advantage of extending stable growth for long-term measures.

2. The labor-intensive, high-cost tank cultures make field farming an attractive low-cost alternative. The next logical step was to test tank growth results against growth under field conditions. Racks of algae were placed in a gradient of exposure at low (+ 1.5 ft), mid (+ 3.0 ft), and high (+ 5.0 ft) intertidal sites (figure 3). Both photosynthesis and growth were monitored for these in-

dividuals. Photosynthetic performance was highest for low intertidal transplants (mean = 6.93 $\mu mol/m^2$ s) and lowest for high intertidal individuals (mean = 2.84 $\mu mol/m^2$ s). This time, photosynthetic response describes a linear decline with increasing exposure (figure 4) (n = 18, df = 16, R^2 = 0.834, $p < .001$, Y photosynthetic performance = -0.880 ft. intertidal height + 7.838). Table 1 documents other physiological changes which also follow this trend: fresh weight of plant/cm^2 and desiccation tolerance of photosynthesis. Seasonal changes in exposure must also be considered.

Porphyra growth in response to field conditions did not follow trends established by physiological measurements for the same plants. High intertidal plants, with lowest measured photosynthetic performance, were the only group to show any net growth after 10 days in new field conditions. Mid and low intertidal plants, exposed to greater wave action, did not regain positive growth after 10 days. Epiphyte densities were also greater on plants transferred to lower intertidal ranges, repeating epiphyte density observations made of natural plant populations at these tidal heights (figures 5 and 6). At 20 days, photosynthesis measurements declined for low intertidal plants. This correlates with an increase in epiphyte density. It is clear from this experiment that seasonal physical factors, such as wave action, can significantly modify net growth of plants. As a result of this study, the best site for field culture is a tidal height which imposes enough exposure for epiphyte control (approximately 2 hours a day) but does not impose severe seasonal stress for macroalgal growth. Best tidal heights can be expected to change with seasonal and tidal exposure level changes.

3. Epiphyte colonization, identification, and desiccation sensitivity experiments form the third part of this report. Recruitment of diatoms on four surface types was studied (filter paper, plastic, killed, and living *Porphyra*). We observed epiphyte attachment on all substrates after 24 hours, with maximum colonization occurring on continuously submerged substrates. Living *Porphyra* supported a more diverse epiphyte community than did other substrates, and was also colonized by many protozoans.

Table 2 lists the species of diatom epiphytes found in tank and field transplant culture. The same taxa occurred under both conditions, although tank culture favored rapid growth of long *Fragilaria* and *Melosira* stands. Observations of *Porphyra perforata* grown in culture tanks demonstrates that diatoms can make up as much as 50% of plant net weight. Figures 7 through 10 show scanning electron microscopic details for select species.

Fragilaria californica, our most troublesome tank epiphyte, has its photosynthetic recovery drastically impaired by mild desiccating conditions (figure 11). The host plant, *Porphyra perforata*, is photosynthetically tolerant of a near threefold desiccation level. From this differential tolerance to desiccation, based on photosynthetic measurements, it is clear that tank or field desiccation offers a significant biological control of unwanted epiphytes. Users of this technique must consider the exposure tolerances of both host and epiphytes, with the complication of seasonal variations in these tolerances.

Table 1

Characteristics of Mid Intertidal *Porphyra perforata* Thalli and Photosynthesis after Transfer to New Tidal Heights

Tidal height	Weight/area (mg/cm^2)	% Recovery after desiccation shock
+ 1.5 feet	12.01 + 0.36	50.01
+ 3.0 feet	10.43 + 0.96	68.34
+ 5.0 feet	9.36 + 0.29	96.99

Table 2

Diatom Species Found as Epiphytes on *Porphyra perforata*

Achnanthes longipes Agardh
Achnanthes species #2
Biddulphia longicrurus var. *hyalina* (Schrod.) Cupp
Cocconeis species #1
Cocconeis species #2
Coscinodiscus radiatus Ehr.
Fragilaria californica Grunow
Grammatophora marina (Lyng.) Kutz
Licmorpha abbreviata Agardh
Melosira moniliformis (Muller) Agardh
Navicula species #1
Nitzschia biblobata var. *minor* Gronow
Nitschia closterium (Ehr.) W. Smith
Nitschia species #3
Nitschia species #4
Synedra species #1

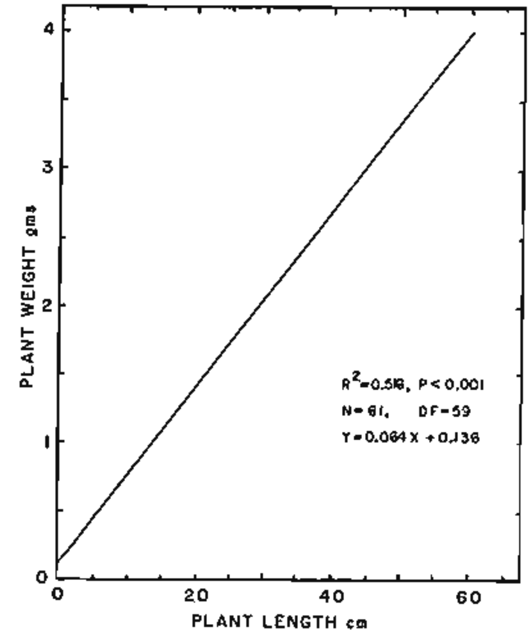


Figure 1. Length to weight correlation for *Porphyra perforata* thalli.

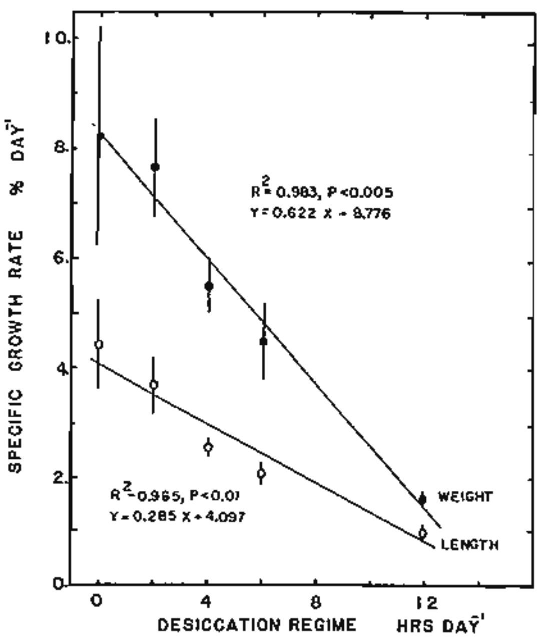


Figure 2. Growth of *Porphyra perforata* as a function of air exposure time in tank culture experiments.

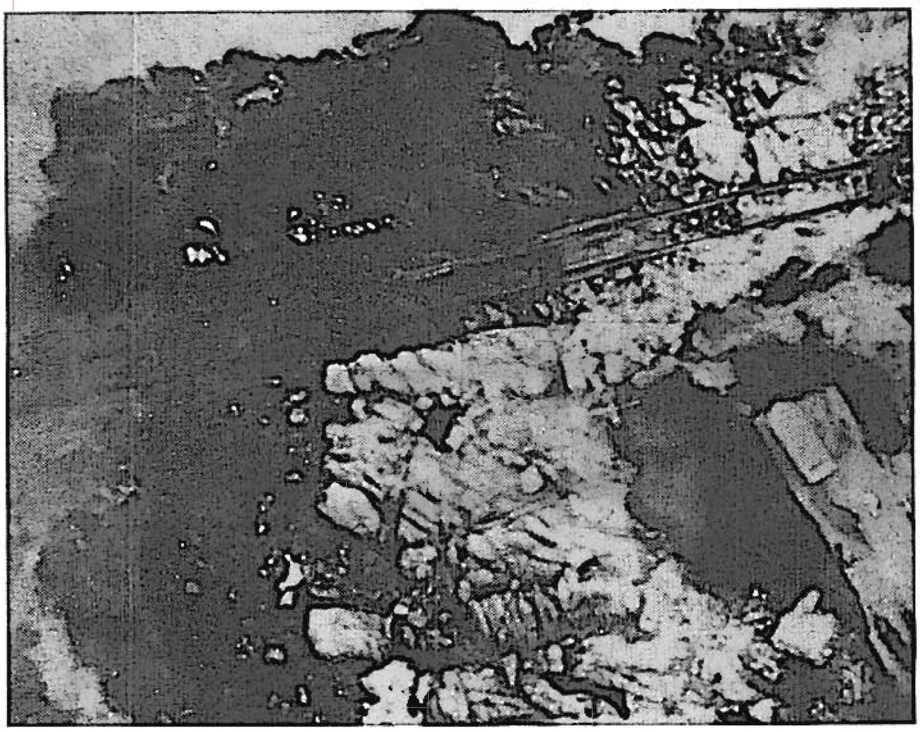


Figure 3. Intertidal gradient sites for rack culture experiments at Hopkins Marine Station, Pacific Grove, California. High (A), mid (B), and low (C) intertidal sites were chosen along a marine railway to give a range of field exposure conditions.

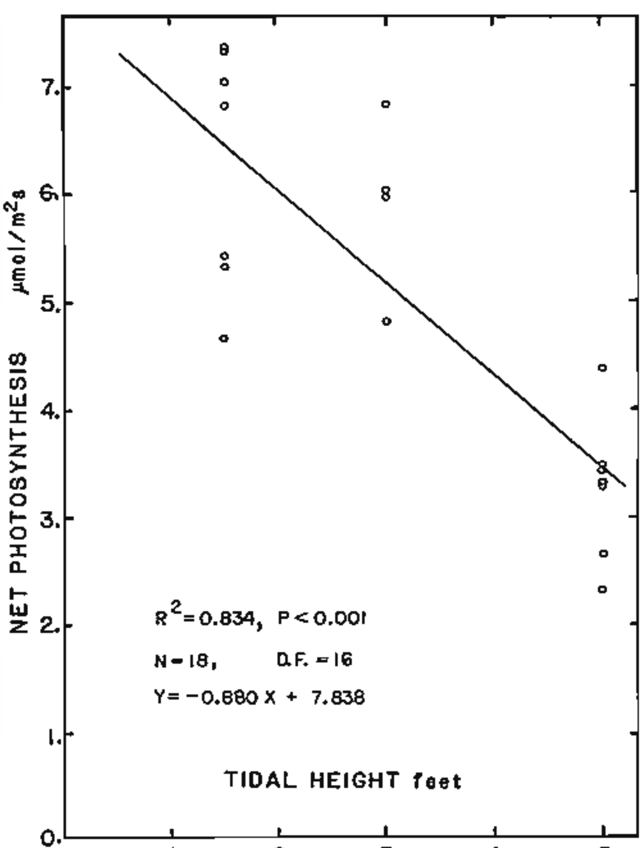


Figure 4. Photosynthetic performance of *Porphyra perforata* in response to intertidal exposure in rack culture experiments.

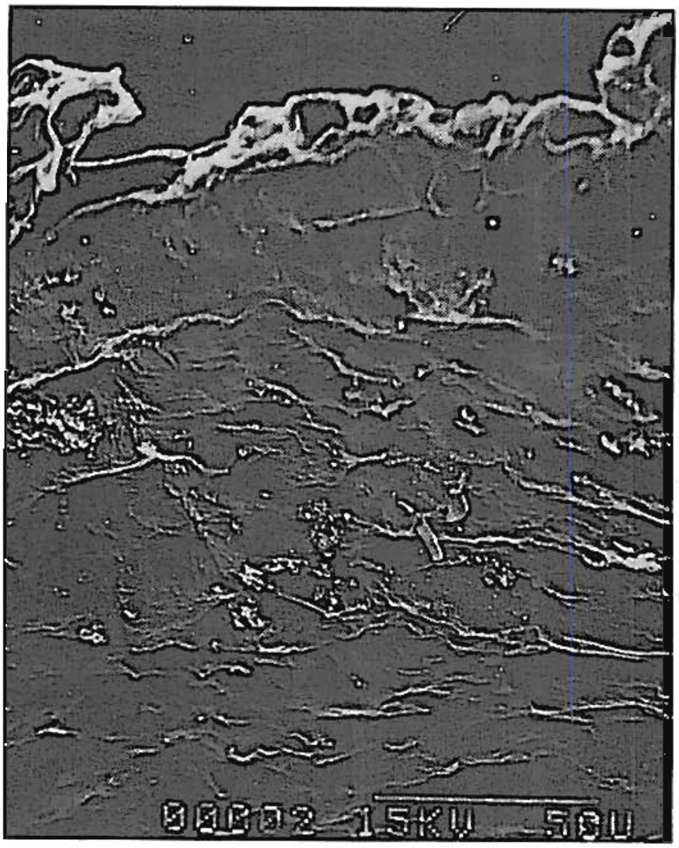


Figure 5. Typical epiphyte density for upper intertidal *Porphyra perforata* thalli. (X 250 magnification)

Figure 6. Typical epiphyte density for low intertidal *Porphyra perforata* thalli, with abundant *Licmorpha* and *Cocconeis* epiphytes. (X 250 magnification)

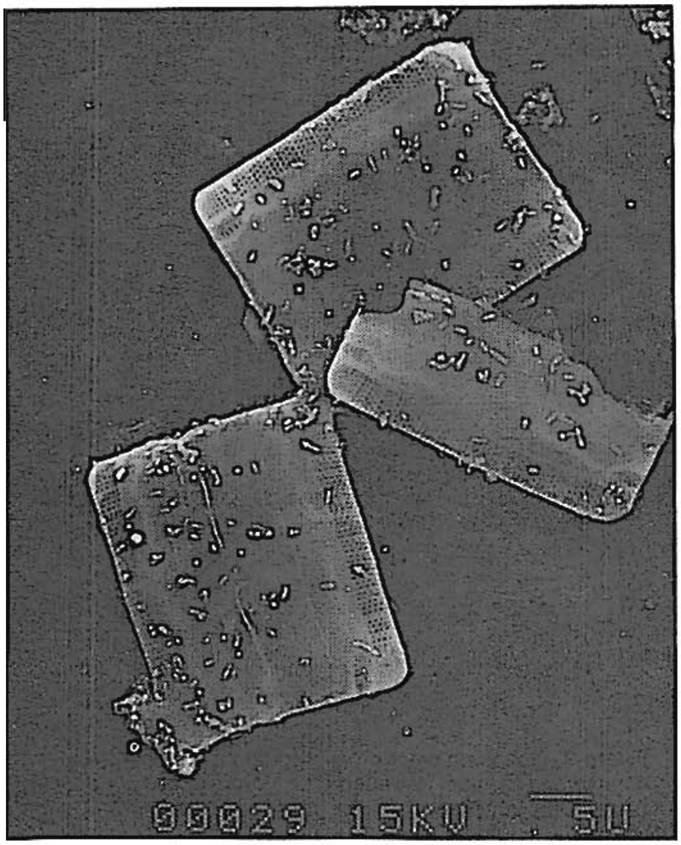


Figure 7. Scanning electron micrograph of epiphytic diatom *Grammatophora marina* isolated from *Porphyra perforata* thalli. (X 1.5 K magnification)

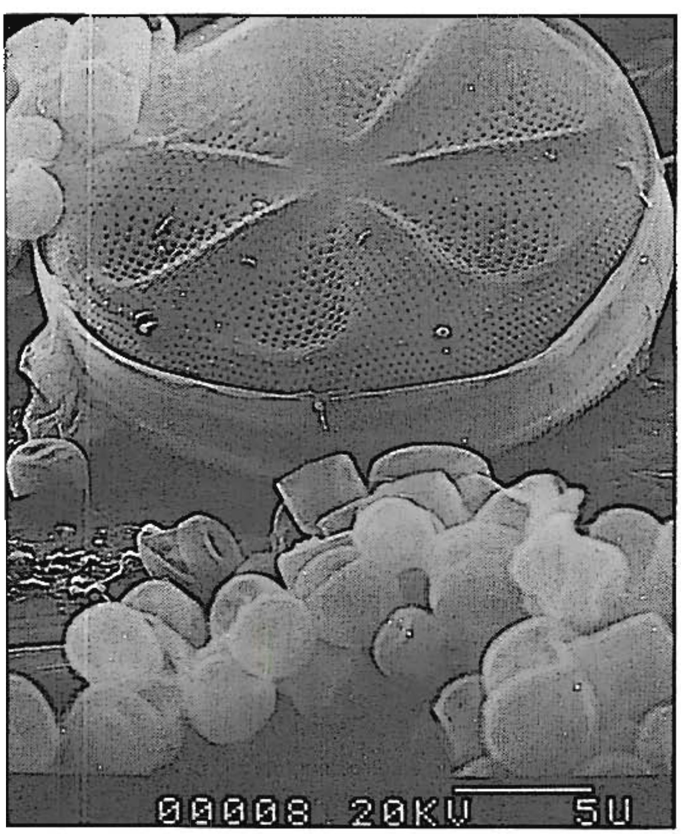


Figure 8. Scanning electron micrograph of epiphatic diatom *Coscinodiscus* sp. with an unidentified small pennate diatom, both isolated from *Porphyra perforata* thalli. (X 3.3 K magnification)

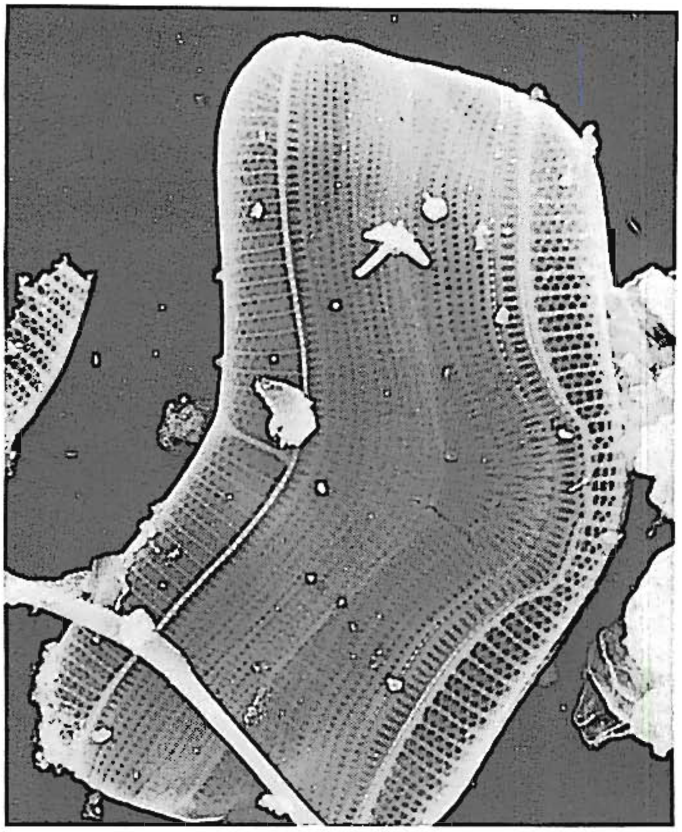


Figure 9. Scanning electron micrograph of epiphytic diatom *Achnanthes longipes*, isolated from *Porphyra perforata* thalli. (X 1.5 K magnification)

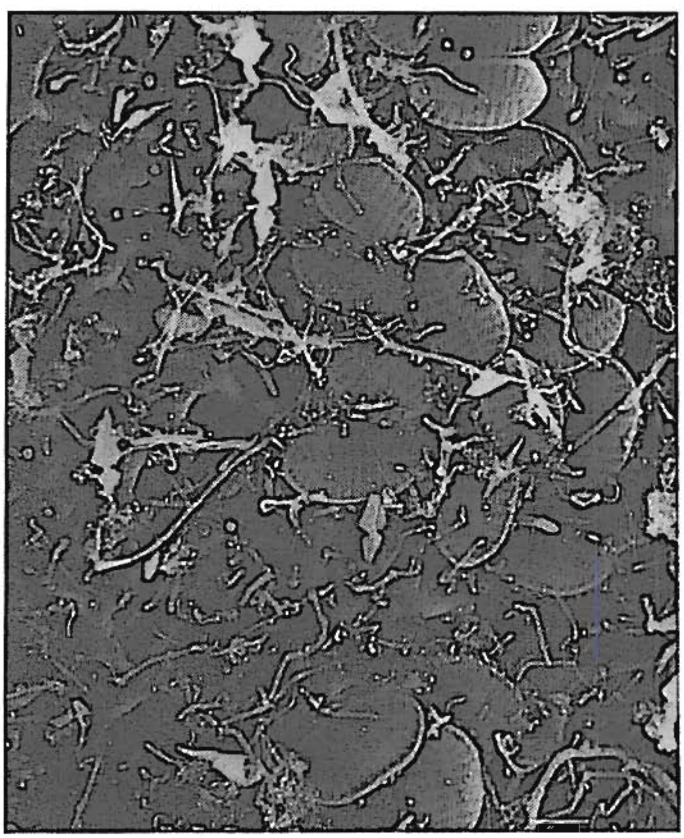


Figure 10. Scanning electron micrograph of epiphytic diatom *Cocconeis* sp., present on surface of *Smithora naiadum* thalli. (X 1.5 K magnification)

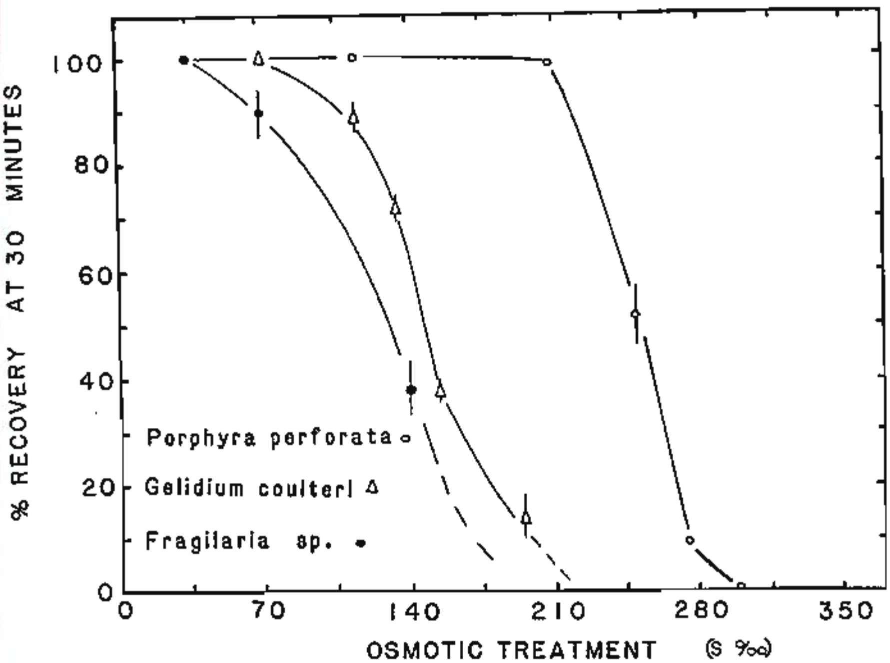


Figure 11. Photosynthetic recovery following desiccation stress by select intertidal algae and algal epiphyte *Fragilaria californica*.

Cooperating Organizations
Carnegie Institution of Washington, Department of Plant Biology

Publications

Abbott, I. A. 1982. Are physiological tolerances significant in defining intertidal zonations of marine algae? Presented at University of New Hampshire, Jackson Estuarine Laboratory.

Abbott, I. A. 1982. Aspects of the physiological ecology of intertidal algae. Presented at University of California, Davis.

Abbott, I. A. 1982. Intertidal algal zonation from a physiological ecology perspective. Presented at Moss Landing Marine Laboratories.

Abbott, I. A. 1982. Osmotic acclimation by the intertidal red alga, *Porphyra perforata*. Presented at the American Society of Plant Physiology Meetings, Western Division.

Abbott, I. A. 1982. Photosynthetic performance in response to environmental stresses by intertidal algae. Presented at University of California, Berkeley.

Abbott, I. A. 1982. Photosynthetic tolerance to intertidal temperature and osmotic stress by select intertidal marine algae. Presented at Hopkins Marine Station.

Abbott, I. A. Photosynthetic adaptation and acclimation to intertidal stress by intertidal red algae. Presented at Carnegie Institution of Washington.

Abbott, I. A. and Van Keuren, D. Desiccation control of epiphytes in an algal mariculture system. (In prep.).

Abbott, I. A. and Van Keuren, D. The effects of desiccation on growth of *Porphyra perforata* in tank culture and in the field. (In prep.).

FISHERIES

DEVELOPMENT OF MULTISPECIES MANAGEMENT FOR KELP BED RESOURCES WITH AN EMPHASIS ON SEA URCHINS

University of California, San Diego
R/F-36
1980-81

Mia J. Tegner and Paul K. Dayton

Sea urchins are functionally the most important herbivores in the kelp forests of southern California and many temperate seas; their grazing activities can profoundly affect the distribution and abundance of numerous other organisms. The recent history of kelp beds in this region emphasizes the recurrent episodes of destructive sea urchin grazing and demonstrates the serious limits of single-species management or laissez-faire economic schemes. An understanding of the natural controls of sea urchin abundance and distribution is important, not only for managing the red sea urchin (*Strongylocentrotus franciscanus*) fishery but also for formulating a multispecies approach to management of all kelp forest resources.

Competition and predation are interactions with other species which have the potential for regulating the abundance and distribution of an organism's population. For the case of sea urchins in southern California, fisheries have heavily impacted populations of both potential competitors (the abalones, members of the genus *Haliotis*) and predators (the sea otter, *Enhydra lutris*; the spiny lobster, *Panulirus interruptus*; and the California sheepshead, *Semicossyphus pulcher*). While it is well known from studies in California and Alaska that sea otter predation keeps sea urchin populations at very low levels, sea otters had been gone from southern California for more than a century when destructive sea urchin overgrazing was first recognized as a major problem. Clearly other factors were affecting urchin populations in the intervening period (Tegner, 1980).

We investigated the interactions between red sea urchins and red abalones (*H. rufescens*), the conspicuous large invertebrate herbivores of southern California kelp forest communities (Tegner and Levin, 1981). These animals co-occur and are often found close together on the same reefs. They employ the same primary mode of feeding, show similar food preferences and are both nocturnal. Competition for food was analyzed in long-term laboratory experiments comparing growth at three different food levels. Large red abalones tended to depress the growth rates of large red urchins even in the presence of excess food. Small urchins were unaffected by competition. Red urchins are physiologically and behaviorally better adapted to cope with limited food supplies. The urchins are about 1.5 times more efficient than red abalones at converting both organism's preferred food, *Macrocystis*, to body weight. While the two grazers showed no difference in time to starvation in the laboratory, the urchins' more aggressive foraging behavior and more generalist feeding strategy suggest that they would do better than abalones during food shortages.

Our data do not indicate that competition with red abalones is likely to be a major factor regulating red urchin populations, but the consistency of trends in the laboratory growth experiments argue that weak competitive interactions are real. Abalones may be able to decrease the urchins' relative fitness when food supplies are adequate through interference competition. Yet even with the greatly increased abalone standing stocks of the past, competitive exclusion would be unlikely because of the red urchins' more opportunistic characteristics: better abilities to cope with food stress, higher reproductive rates, and wider dispersal. Nevertheless, competition may have been more important in the past when larger standing stocks of both herbivores and their predators limited both food and space resources and made foraging tactics and habitat selection more critical (Tegner and Levin, 1981).

In contrast, the case for predation affecting the distribution and abundance of sea urchins is strong. Our field studies (Tegner and Dayton, 1981) in the Point Loma kelp forest near San Diego showed that red urchin population structure is different in areas where lobsters and sheepshead are common from areas where these predators are absent. Urchin test collections of natural mortalities, small scale urchin distribution patterns, and grazing mortality of *Macrocystis* all suggest that lobsters and sheepshead control urchin populations. Representative red and purple (*S. purpuratus*) urchin population structures from an area where these predators are common are shown in figure 1. (Because the population structures were similar from year to year, the data were summed for the entire study; see Tegner and Dayton, 1981 for details.)

A major focus of our efforts this past year has been to understand the interactions between red and purple sea urchins and their predators and to explain the observed population structures and higher rates of predation in purple sea urchins. Spiny lobsters, more amenable for work in aquaria than sheepshead, were used for an extensive series of feeding experiments. The lobsters showed a strong preference for purple urchins over their longer-spined congeners ($X_1^2 = 10.8$, $p \leqslant .005$). Within each species, smaller urchins are preferred over larger urchins, but purple urchins under 60 mm are preferred over even the smallest red urchins. Large and mid-sized lobsters, which are capable of handling large red urchins ($\geqslant$100 mm), showed a distinct preference for red urchins less than 60 mm when presented with a range of sizes. The largest lobsters were somewhat more likely to take sea urchins between 60 and 90 mm. None of the lobsters chose urchins larger than 90 mm as their prey. Earlier we described the unusual nursery association of small red urchins spending about their first year of life under the spine canopies of conspecific adults, an association which enhanced the settlement and survival of juveniles in the field (Tegner and Dayton, 1977). We tested the effects of the adult spine canopies on lobster predation of small red urchins in the laboratory and found that the presence of the canopy clearly inhibits predation ($X_3^2 = 9.8$, $p \leqslant .025$).

Thus the bimodal size-frequency distribution of red urchins can be explained by lobster predation patterns. The first peak is accounted for by protection of juveniles under the spine canopy and the region between the peaks represents the most vulnerable size category. The reluctance of even large lobsters to take on large red urchins shows that the second peak represents a partial refuge in size. This peak is large despite heavy predation on intermediate sized urchins because several year classes are accumulated here as growth rates slow down. Purple urchins, which make little use of the spine canopy association and do not attain any refuge in size, are unimodal. Lobster preferences for the shorter-spined purple urchins in the lab show the importance of handling considerations and explain the higher predation rates observed in the field.

In an attempt to determine the relative importance of lobster versus sheepshead predation in the field, an experiment was initiated last spring near Point La Jolla. The observation that sheepshead are active by day and urchins at night suggests the urchins' behavior pattern may have evolved as a response to the predation pressure of this fish. All of the sheepshead were removed from the area surrounding an isolated reef and migrants are being removed monthly. Lobsters are not being manipulated. If sheepshead are the more important red urchin predators, we would expect to see a substantial reduction of the bimodality in their population structure in about a year's time. Studies of the gut contents of sheepshead removed from this reef show that urchins are their major food item.

Further verification of the importance of lobster and sheepshead predation comes from several years of data from Channel Island populations. Red urchin populations on San Clemente and Santa Barbara Islands are consistently, strongly bimodal and these predators are common to abundant. At Santa Rosa and San Miguel Islands, these predators are both at the northern end of their distributions and are uncommon or absent. Red urchin populations are not bimodal in these areas. The size of red urchin populations on the southern islands appears to be regulated by predation on mid-sized animals and in the north by the success of recruitment to benthic populations.

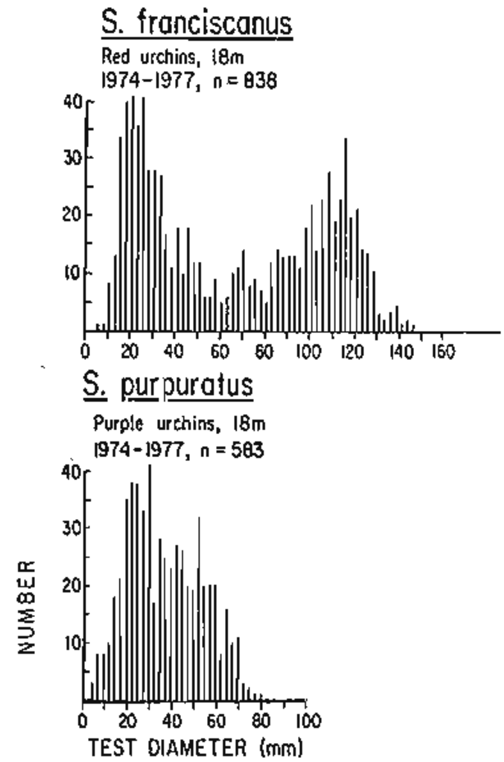


Figure 1. Representative red, *Strongylocentrotus franciscanus*, and purple, *S. purpuratus*, sea urchin size-frequency distributions from an area in Point Loma where two important predators, the spiny lobster, *Panulirus interruptus*, and the California sheepshead, *Semicossyphus pulcher*, are common. The bimodal nature of red urchin populations results from protection of juveniles by the spine canopy association, the high vulnerability of intermediate sized animals to predation, and a partial refuge from predation in size by large adults. Purple urchins, which make little use of the spine canopy association and have no refuge in size, characteristically exhibit a unimodal population structure.

Cooperating Organizations

California Department of Fish and Game

References

Tegner, M. J. 1980. Multispecies considerations of resource management in southern California kelp beds. Canadian Technical Report of Fisheries and Aquatic Sciences 954:125-143.

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

Publications

Tegner, M. J. and Dayton, P. K. 1981. Population structure, recruitment and mortality of two sea urchins (*Strongylocentrotus franciscanus* and *S. purpuratus*) in a kelp forest. Mar. Ecol. Prog. Ser. 5:255-268.

Tegner, M. J. and Levin, L. A. (Submitted). 1981. Do sea urchins and abalones compete in California kelp forest communities? In *Proceedings, International Echinoderm Conference.* Tampa Bay, Florida, September 1981.

ENDOCRINOLOGY OF NORMAL AND ABNORMAL SALMON SMOLTIFICATION AND ADAPTATION TO SEAWATER

University of California, Berkeley
R/F-45
1980-81

Howard A. Bern

This year various aspects of the morphological and physiological changes accompanying coho salmon smoltification have been studied using fish from the Iron Gate Hatchery near Eureka in northern California. Preliminary studies on king salmon were begun. Fish were sampled from January to June, generally every 2 weeks and coincident with the new and full moons. Much of our emphasis has been on thyroid function and the influence of various hormonal and environmental factors thereon.

An ultrastructural study of certain endocrine glands of the coho salmon, conducted in order to assess their activity during normal and abnormal smoltification, has been completed. Emphasis was placed on those endocrine cells and glands considered important in the smoltification process. Prolactin cells appeared active in normal smolts and inactive in the (seawater) stunt, but growth hormone cells appeared active in all groups. Thyrotropin cell activity was reduced in the stunt, and the thyroid epithelium was clearly atrophic. Similarly, the corticotropin cells in the stunt exhibited diminished activity compared with the cells of normal smolts, and the interrenal cells appeared clearly inactive with deformed mitochondria, sparse smooth and rough endoplasmic reticulum, and limited membrane development at the vascular pole. Other endocrine glands of the stunt, including the ultimobranchial, pancreatic islets, and caudal neurosecretory system, showed generally diminished activity in comparison with normal fish. In many respects, the abnormal stunt appears to be hypoendocrine; however, the growth hormone cells and the corpuscles of Stannius showed ultrastructural signs of appreciable activity.

In California it was determined that the thyroxin surge occurred on the new moon closest to the vernal equinox in previous years. This year a sampling schedule was designed to be particularly intensive at the new moons likely to be the times of the thyroxin surge. Because a full moon fell on the vernal equinox, a rare event which results in the equal spacing of two new moons about the equinox, the thyroxin surge would have an equal probability of occurring at either new moon. Two peaks indeed occurred on each of the new moons in March and April. It now appears that the smoltification-related thyroxin surge includes two components: a slow rise which occurs over several months and a "spike" release which occurs in coincidence with the new moon. The most striking feature of the spike phase is the abruptness of the surge, which occurs within 5 days and possibly much less time. Sampling frequency will be increased in 1982.

We planned to test whether downstream movement is correlated with the rise in thyroxin on the new moon nearest the vernal equinox. A study utilizing the smolt-trap devised by Kerstetter was begun in mid-February, 1981. Two thousand coho salmon presmolts were put into a raceway with a smolt-trap installed at its lowest end. However, after the first two samples were taken, the raceway was vandalized and about 1500 fish were stolen or destroyed just prior to the new moon in March. If indeed coho salmon show a propensity to move downstream through the smolt-trap in conjunction with the new-moon-associated thyroxin spike, a volitional release study can be readily planned using this technique; a more extensive study is planned for the spring of 1982.

In order to determine the effect of timing the release of coho salmon smolts on their ability to survive and grow in seawater, more than 300,000 binary-coded wire nose-tagged coho salmon have been released from two northern California hatcheries. Release dates were chosen in consultation with our laboratory, based on the lunar hypothesis of the smoltification-associated thyroid hormone spike. Inasmuch as coho salmon spend 2 to 3 years at sea before returning to spawn, it will be some time before the relative appropriateness of the several release dates can be assessed. Tagged releases will continue in 1982 and 1983.

King salmon which are retained in fresh water undergo multiple thyroxin spikes (all coincident with the new moon). In terms of king salmon enhancement, the multiple thyroxin spikes may serve as several opportune times for hatchery release. We plan to suggest a controlled release of tagged fish at selected dates based on the lunar calendar comparable with what is being done at present with coho salmon.

In a developmental study of the structure of the thyroid gland in coho salmon, we examined its histological and ultrastructural features during smoltification. Histological observation of 1-μm-thick sections showed that the height and the number of nucleoli of follicular cells increased from January to March, decreased in April, then increased again in May. Ultrastructural observations revealed that starting in late winter, thryoid follicle cell organelles showed increased development until mid-April and decreased thereafter. Thyroid ultrastructural features were in accord with plasma thyroxin levels as indicators of thyroid activity.

A histological and ultrastructural study of the influence of thryotropin on thyroid gland morphology at two time periods during coho salmon smoltification was completed. Using graded doses of bovine thyrotropin ranging from 0.05 to 0.8 IU, fish were injected daily for 4 days and killed on day 5. Plasma thyroxin values were directly related to thyrotropin dosage and ranged from 0.64 ng/ml in controls to 24.5 ng/ml in maximally stimulated fish. Histological examination revealed that thyrotropin treatment increased the thickness of follicular cells, the size of the nucleus and the number of nucleoli. Thyrotropin decreased the electron density of follicular cell cytoplasm, but increased cell height and quantity of rough endoplasmic reticulum including ribosomal rosettes, smooth endoplasmic reticulum, lipid droplets, formation of lobules from the apical membrane, and the number and size of mitochondria and Golgi bodies. These changes are similar to those described in other vertebrates and provide a basis for determining the level of thyroid gland activity.

A study of the clearance kinetics and plasma concentration of thyroxin in response to thyrotropin and seawater entry during smoltification was conducted in order to determine whether the decrease in plasma throxin following entry of smolt-age salmon into seawater results from inhibition of thyrotropin release, changed effectiveness of thyrotropin at the level of the thyroid tissue, or from increased clearance of thyroxin. The maximum response to 0.1 IU thyrotropin occurred at 24 hours. Thyroxin levels were higher in fish from fresh water than in those from seawater in both thyrotropin-injected (50.9 ± 15.7 vs. 20.1 ± 8.3 ng/ml) and saline-injected (11.7 ± 1.3 vs. 4.3 ± 0.9 ng/ml) groups. We also determined that the rate of clearance of thyroxin from the plasma of fish injected with 0.1 IU thyrotropin and placed in seawater was 54.0 ml plasma/hour compared with 20.7 ml plasma/hour for fish placed in fresh water.

Chronic effects of transfer into seawater on plasma sodium and thyroxin levels was conducted over the entire course of coho smoltification. Fish were transported to Berkeley and acclimated for 24 hours and an initial blood sample was taken. One group was placed directly in seawater and the control group was placed in fresh water. Blood samples were taken at 24 hours, 3 days, 6 days, 12 days, and 28 days after transfer. Preliminary results show that direct entry into seawater causes a surge in plasma sodium levels (at 24 hours); over the longer time course, plasma sodium returns to the level of the freshwater group. An immediate drop in thyroxin also occurs; levels at later times have yet to be determined.

Prolactin effects on the clearance kinetics and plasma concentration of thyroxin show that it does not significantly change thyroxin titers. However, the kinetics data are irregular, suggesting that something of potential interest is occurring. We plan to alter our experimental protocol and pursue this topic during the next smoltification period.

Trout reared in blue tanks become silvery and also more tolerant to seawater transfer. The objective of our study was to determine whether coho salmon would undergo similar changes and whether these changes correlate with thyroid gland activity. As soon as the data analysis is complete, we shall be able to determine if the salmon silver earlier in blue tanks and whether this silvering reflects true smoltification or is merely a pigmentary response to the blue background color.

We continue our studies of epithelial transport using a variety of fish membranes in order to elucidate the ways in which hormones act to alter ion and water transport in preparation for migration to the ocean. Changes in osmoregulatory mechanisms compatible with seawater entry, including the plateauing of increases in intestinal fluid transport, increase in opercular chloride-secreting cell numbers, and the abolition of salt resorption by the urinary bladder all appear to occur 2-4 weeks after the thyroxin spike. These data suggest that osmoregulatory competence for seawater survival and growth may be phase-related to the thyroxin spike.

Efforts to characterize salmon prolactin and growth hormone are continuing. Using our prolactin bioassay system, which exploits the plasma sodium-retaining effects of prolactin in the hypophysectomized teleost fish *Fundulus heteroclitus*, we have characterized and identified a prolactin-like hormone from the coho salmon rostral pars distalis. Based on SDS gel electrophoresis and isoelectric focusing, this molecule appears to be similar to those purified by Kawauchi (Kitasato University, Japan) and by Prunet (Laboratory of Fish Physiology, Rennes, France) from chum and king salmon, respectively. These proteins have molecular weights in the range of 20,000-24,000 and isoelectric points near pH 9. Our bioassay system shows the promise of becoming the basis on which present and future attempts to produce large quantitities of salmon prolactin can depend.

We have collected an additional 1,000 coho salmon pituitaries, separated into rostral and proximal parts of the pars distalis. These will be employed by our collaborator, Martial, at the University of Liege in Belgium, toward the sequencing and possible production of coho prolactin and growth hormone using gene insertion techniques. In an initial study using the two parts from 600 pituitaries, molecules of approximately 22,000 MW (compatible with the two hormones) have been produced. If the genes for these molecules can be successfully inserted into a suitable bacterium, and the biological activity of the prohormonal products established, a supply of coho salmon prolactin and growth hormone may become available in meaningful amounts.

Robert Rawstron, the newly appointed chief of the Anadromous Fish Branch of the California Department of Fish and Game has selected a committee of five members representing the different Fish and Game regions to come up with specific recommendations for the improvement of hatchery practices that could be implemented as early as 1982. Selected were four members of California Fish and Game and either Nishioka or Grau from UC Berkeley to help implement timing of release based on lunar cycle-associated thyroxin spikes and the advantages of using "smolt-trapping" for volitional release directly or indirectly from the hatchery.

Cooperating Organizations
California Department of Fish and Game
Kitasato University, Japan
Laboratory of Fish Physiology, Rennes, France
National Marine Fisheries Laboratory
National Science Foundation
University of Liege, Belgium
University of Tokyo, Japan

Publications

COLLIE, N. L. AND BERN, H. A. 1980. Variations in water transport across the coho salmon posterior intestine during smoltification. Am. Zool. 20:764. (Abstract).

GRAU, E. G. 1980. Some aspects of thyroid physiology during the smoltification of Pacific salmonids. Fifth meeting, Japan Society for Comparative Endocrinology, Toyama, Japan, October 1980. (Abstract).

GRAU, E. G. In press. Is the lunar cycle a factor timing the onset of salmonid migration? In *Proc., Symposium on Salmon and Trout Migratory Behavior.* College of Fisheries, University of Washington, Seattle, June 1981.

GRAU, E. G., DICKHOFF, W. W., NISHIOKA, R. S., BERN, H. A., AND FOLMAR, L. C. 1981. Lunar phasing of the thyroxine surge preparatory to seawater migration of salmonid fish. Science 211:607-609.

GRAU, E. G., NISHIOKA, R. S., AND BERN, H. A. 1980. Effects of seawater (SW) entry on thyroid function in the coho salmon *Oncorhynchus kisutch.* Am. Zool. 20:857. (Abstract).

GRAU, E. G., SPECKER, J. L., NISHIOKA, R. S., AND BERN, H. A. 1982. Factors determining the occurrence of the surge in thyroid activity in salmon during smoltification. Aquaculture 28(1-2):49-58.

LAI, K. V., GRAU, E. G, NISHIOKA, R. S., AND BERN, H. A. 1980. Influence of TSH upon structure of thyroid gland in coho salmon. Am. Zool. 20:857. (Abstract).

LORETZ, C. A., COLLIE, N. L., RICHMAN, N. H., III, AND BERN, H. A. 1982. Osmoregulatory changes accompanying smoltification in coho salmon. Aquaculture 28(1-2):67-74.

NAGAHAMA, Y., ADACHI, S., TASHIRO, F., AND GRAU, E. G. 1982. Some endocrine factors affecting the development of seawater tolerance during the parr-smolt transformation of the amago salmon *Oncorhynchus rhodurus.* Aquaculture 28(1-2):81-90.

NISHIOKA, R. S., BERN, H. A., LAI, K. V., NAGAHAMA, Y., AND GRAU, E. G. 1982. Changes in the endocrine organs of coho salmon during normal and abnormal smoltification — an electron-microscope study. Aquaculture 28(1-2):21-38.

NISHIOKA, R. S., GRAU, E. G., AND BERN, H. A. 1980. Growth hormone release *in vitro* from the pituitary gland of tilapia *Sarotherodon mossambicus.* Am. Zool. 20:859. (Abstract).

SPECKER, J. L. 1982. Interrenal function and smoltification. Aquaculture 28(1-2):59-66.

EXPERIMENTAL ABALONE ENHANCEMENT PROGRAM

University of California, San Diego
R/F-47
1980-81

Mia J. Tegner

The objectives of this program are to develop an understanding of the natural history and ecology of the major species (red, *Haliotis rufescens*; pink, *H. corrugata*; and green, *H. fulgens*) of abalones in southern California and to use this knowledge to design and execute four experimental approaches aimed at determining the scientific and economic feasibilities of enhancing abalone populations in depleted areas. The four approaches are seeding hatchery-reared juveniles, habitat modification to provide nursery areas, fishing closures to allow natural recovery, and transplantation of adults as broodstock.

Seeding of hatchery-reared juveniles to enhance fishable standing stocks is an approach pioneered and practiced on a very large scale by the Japanese. Seeding experiments testing size-specific survivorship, the effects of habitat type on survival (including offshore as compared to mainland sites), the effects of density on dispersal, and the effects of different planting methods have been initiated for red and green abalones. The hatcheries have not been able to solve the problems associated with the production of pink abalones, so this species has been dropped from the program.

Five large-scale experiments are underway with red abalones. Two experiments on the Palos Verdes Peninsula with medium sized seed were designed to test survivorship in different habitat types. Lunada Bay I is located in a somewhat protected cove which supports an extensive *Macrocystis pyrifera* forest. Point Vicente, receiving considerably more water motion, is characterized by the lower standing palm kelp, *Eisenia arborea*. Our major test of size-specific survivorship and clean water control to the Palos Verdes Peninsula was established at Tyler Bight on San Miguel Island. About 10,000 abalones in each of four size classes (11, 20, 28, and 34 mm) were planted in 1979. Because it was very difficult for a diver to handle the smallest seed, we designed a test to compare survival of hand-planted seed versus those on artificial substrates. In Lunada Bay II, 5,000 red abalones averaging 13 mm were planted in our standard manner and 5,000 more were allowed to attach to oyster shell prior to transport from the hatchery and were planted by placing the artificial substrate in cryptic spots. Reconnaissance dives 1 and 2 days after this plant suggest that immediate survivorship was comparable for the two methods despite large differences in the amount of handling stress the animals received. The advantage of the oyster shell method is a 2/3 reduction in the effort required for planting. A disadvantage may be a tendency of the seed to remain on the shell.

Inoue, of the Kanagawa prefectural laboratory in Japan, found that survivorship of planted *H. discus* seed levels off at 70% for 40 mm animals (personal communication). Because our hatchery had been unable to supply us with 40 mm animals for the San Miguel experiment, we seeded 175 red abalones averaging 45 mm and 501 averaging 71 mm into an area near Palos Verdes Point this spring. Although the experiments were initiated at different times, we have now planted five size categories of red abalones at Palos Verdes; these data will augment the size-specific survivorship results from San Miguel. The obvious factor varying with abalone size is the amount of effort required for a predator to handle its prey; shell thickness increases with size providing increasing degrees of refuge from predation. Our results show that movement also varies with size. Mapping experiments indicate that the larger the seed size, the slower the dispersal rate fron planting sites. Since abalones are more vulnerable to predation when they are not firmly attached to the substrate, differential dispersal rates as well as changing shell thickness are likely to contribute to size-specific variations in survivorship.

Lunada Bay I, the first large-scale experiment, was seeded with 10,500 red abalones in 1978 and has been resurveyed annually for live animals and shells. While we found few live animals in the most recent survey, the seed are still in a cryptic size category and are difficult to sample. Data from native populations suggest that red abalones become emergent between 120 and 150 mm, thus the Lunada Bay I animals should be more readily assessable in late 1981 or 1982. The fact that we have not found large numbers of shells and that the few shells we have found are larger each year further suggest that we are not able to adequately sample cryptic-stage red abalones. The results from Lunada Bay I will be used to determine the optimal time for evaluating the other red abalone seeding experiments.

No attempts were made to manipulate predators during the initiation of the Lunada Bay I seeding experiment and 173 shells were found within the first month. Field observations and laboratory experiments indicated that crabs (*Cancer* sp. and *Loxorhynchus grandis*), lobsters (*Panulirus interruptus*), octopuses (*Octopus* sp.), gastropods (especially *Kelletia kelletii*), starfish (*Astrometis sertulifera* and *Pycnopodia helianthoides*), and the cabezon (*Scorpaenichthys marmoratus*) are the major seed abalone predators. We tried collecting these predators during preplant surveys and the actual seeding process to reduce predator pressure during the critical period of adaptation to a new environment. This procedure, now part of our standard planting techniques, reduced the number of shells found after 1 month at Lunada Bay II to 36.

Two large-scale experiments were initiated with green abalones during 1980-81. Eight thousand seed were planted at two different densities at Haggarty's on the Palos Verdes Peninsula to determine the effects of density on dispersal. About 20,000 greens in a variety of sizes were planted at a site on southeastern Santa Cruz Island. This experiment is our offshore control to Palos Verdes and our test of size-specific survivorship for greens. Work to date shows that hatchery-reared greens (and their size at planting) are clearly distinguishable from native abalones after 1 year in the field, a factor which will greatly facilitate evaluation of both experiments.

Our early studies of abalone natural history suggested the importance of adequate nursery habitat for maintaining red abalone population size. Most juvenile red abalones are found under small, turnable rocks, a habitat which appears to offer maximum protection from predators. This suggests that the addition of nursery rocks to habitats whose physical structure does not offer adequate cryptic shelter for juveniles but which could support larger animals, would improve the survival of both naturally settled and seeded abalones. Southern California Edison requested that the Department of Fish and Game design a multipurpose reef to enhance marine resources in the waters near Camp Pendleton. The objective was to develop and test several designs to see whether such reefs could be used in the future as mitigation for the potential adverse effects of power plants. Using our design specifications, eight reefs were constructed in September, 1980. Four reefs were built with nursery habitat and four without. To our knowledge, these are the first artificial reefs in the United States designed to enhance invertebrate as well as fish populations.

To test the role of nursery habitat for young abalones, two of each type of reef are being seeded with hatchery-reared abalones and two of each type will be used to follow natural recruitment. *Macrocystis* is being transplanted to each reef and other algae are recruiting naturally. A preliminary test plant has shown that red abalones are surviving on these reefs but the full-scale plant has been delayed until new *Macrocystis* transplants are well established. Unusually warm water conditions last spring destroyed the first transplants but conditions have improved and the new transplants appear to be growing. If our hypothesis is correct, habitat modificiation may be an effective approach for enhancing abalone populations in certain areas where poor habitat apparently limits abalone productivity, in addition to providing a new dimension to artificial reefs. 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.

The California Legislature closed the coastline between Palos Verdes Point and Dana Point to the sport and commercial take of abalones for a 5-year period beginning in March 1977. We have censused rocky habitats within the closure and to the north of Palos Verdes Point. If all species are pooled, there are significantly more emergent abalones inside the closed area (t test, $p \leqslant .05$). None of the more highly desired species, reds and pinks, were counted outside the closed area (although they are known to have occurred there) which is comparable in habitat to the closed area. Black abalone densities are 6-7 times higher inside the closed area. Size data also indicate a trend for higher recruitment rates inside the closure, but we have not been able to detect a significant change in the native red or black abalone populations at one location in the closed area over 3 years of sampling. These data suggest that the closure is having an effect but, given the very low densities we are dealing with, more observations will be required to determine the significance of the effects and the rates of change.

A striking result from these censuses is that there are considerably more red than green abalones at Palos Verdes today although both apparently were abundant in the past. If one assumes that abalone populations were reduced to levels too low for effective reproduction to take place during the years when there was no *Macrocystis* and standing stocks of other algae were drastically reduced, then present species compositions should reflect adaptability to present conditions or the relative colonizing abilities of each species. The excellent growth rates we are observing for native and hatchery-reared red and green abalones at Palos Verdes today support the second hypothesis. In an attempt to explain the present species composition and to determine whether the closure approach is feasible for green abalones in the near future, we are conducting a drift-bottle experiment to determine the relative importance of endemic versus external sources of green abalone larvae for the recolonization of Palos Verdes. Drift bottles were released during the two peaks of the green abalone spawning season over the major present and past green abalone beds in southern California. Results from the first deployment suggest that endemic sources of larvae are very important for an organism with a short larval life such as *H. fulgens*. For example, drift bottles from Channel Island sites made it to the mainland but most of the transport times were considerably longer than the life span of a green abalone larvae. If the results from the second deployment are similar, we will recommend to the Department of Fish and Game a large-scale transplant of sublegal, reproductive green abalones into the closed area at Palos Verdes.

In summary, we have learned much about abalone biology and made progress with each of the approaches to population enhancement and have encouraging evidence that some of the approaches will work. However, given abalones' slow growth rates and the 2- to 4-year time lag from initiation of an experiment to the time for meaningful evaluation, it is too early to demonstrate feasibility.

Cooperating Organizations
California Abalone Association
California Department of Fish and Game
Southern California Edison

Publications

TEGNER, M. J. AND LEVIN, L. A. Submitted. 1981. Do sea urchins and abalones compete in California kelp forest communities? In *Proceedings, International Echinoderm Conference*. Tampa Bay, Florida, September 1981.

ECONOMICS OF FISHERIES AND AQUACULTURE DEVELOPMENT

University of California Davis
R/F-52
1980-81

Warren Johnston, Cadet Hand, and Louis W. Botsford

The original aims of the fisheries portion of this project were to describe the biological factors contributing to cyclic fluctuations in the northern California crab fishery, describe the important economic aspects of the fishery, and then, based on these, formulate better management policy. These were later expanded to include a survey of west coast crab populations for the presence of a predator worm. With regard to the cause of the cycles, fluctuations in effort have been ruled out as a mechanism. Remaining potential causes are environmental factors and density-dependent recruitment stemming from either cannibalism, the egg-predator worm, or another as yet unidentified mechanism. With regard to new fishery policy, since the cause of the cycles is not known, these results are preliminary. We have, however, derived a policy that increases returns to the fishery whether the cause is density-dependent or environmental. With regard to the egg-predator worm, samples indicate that it exists at high levels in both California fisheries and in Oregon and Washington.

The starting point of this project was an analysis of multiple age-class, density-dependent recruitment models that showed that a size-selective fishery could render the models unstable, and that the existence of potential unstable recruitment mechanisms could be tested in the field (Botsford and Wickham, 1978). We planned to test two known mechanisms: cannibalism and an egg predator worm, *Carcinonemertes errans*.

Field work on cannibalism began in 1979 in Humboldt Bay by collecting crabs with an otter trawl and analyzing their gut contents. Heavy levels of cannibalism by 1-year-olds on newly settled crabs were observed. These were the only two age classes in the bay in any abundance. In the June sample, out of 48 crabs examined, 10 crabs had remains of 17 young-of-the-year (YOY) crabs. Since laboratory experiments showed that YOY crabs were digested within 24 hours, this was a daily rate. Trawls taken outside the bay showed greater densities of YOY than inside.

In 1980 very few YOY crabs and no 1-year-old crabs were found in Humboldt Bay.

In 1981 sampling was conducted with both trawl and pots from a fishing boat off Trinidad Head. No YOY were caught, but many were found in guts of older crabs. Table 1 shows the high levels observed.

From these studies, which show rates as high as 330%, we can conclude that cannibalism is strong enough to significantly influence abundance. However, to completely evaluate this as a mechanism, we must determine the changes in mortality rates from cannibalism from year to year. These samples will continue at stations outside the bay.

Northern California worm samples have shown that egg mortality from worm predation has increased in recent years (1974-75, 11%; 1975-76, 29%; 1977-78, 30%; 1978-79, 44%; 1979-80, 47%). The likelihood that this mechanism causes the cycles depends on behavior through the next decline in crab numbers and the subsequent increase. From the data gathered thus far we cannot tell whether we have observed an unstable dynamic interaction between crabs and worms, or merely an increase in worms that will remain high in the future.

With regard to the density-dependent recruitment mechanism, McKelvey *et al.* (1980) recently concluded from a modeling study that cannibalism was not the cause of cycles because the observed cycle period did not match the period of cycles produced by their model. This disparity of periods is not new, and was noted in Botsford and Wickham (1978). Our approach has been to test cannibalism in the field rather than reject it on the basis of a model and its assumptions. The logic that led to their conclusion is criticized in Botsford (1981).

Analyses of both the influence of environmental variables and fluctuations in effort in response to abundance require estimates of preseason abundance. These were developed using the Leslie method (Methot and Botsford, submitted). The results (figure 1) show that instead of the smooth, increasing cycles inferred from the catch record, the population actually exhibited much more erratic fluctuations in abundance. This result increases the likelihood that environmental factors are involved. Note that abundance in 1957 was possibly as high as in 1977.

Knowledge of how effort changes from year to year is valuable for two reasons: 1) it may cause cycles (as in predator-prey cycles) and 2) even if not the primary cause, it may influence the causal mechanism. We have shown that neither a predator-prey mechanism nor price-dependent escapement with price depending on past catch causes the cycles in this fishery. The response to cyclic changes in abundance has been a lagged response of effort (i.e., effort does not "track" abundance). This lag decreases as price (deflated) increases. The existence of this response implies that not only are returns from the fishery low in years of low abundance, but they are also lower than the possible level in years of high abundance when effort can't respond to rapid increases. This lagged effort response also causes a density-dependent recruitment mechanism to be less stable and to cause cycles of longer period. The former may be a valuable management tool. The opposite of a lagged effort response, higher effort during high abundance than during low abundance, stabilizes a fishery with density-dependent recruitment. We are evaluating the use of this in management (see later discussion of fishery policy results). The fact that a lagged effort response lengthens the period of the cycles implies that the disparity between observed and computed periods is not as great as previously thought. These results regarding the catch-effort dynamics are in Botsford *et al.* (submitted).

Examination of the size distribution from the preseason cruises of California Department of Fish and Game over the past 30 years has just begun. Increases in the mean size during high periods imply that a low number of year classes (1 or 2) are responsible for each high period rather than the 5 or 6 years seen in the catch.

Two mechanisms were examined that could have caused the decline in the central California fishery. The first is a nemertean worm that preys on dungeness crab eggs. This worm has been at high enough levels to cause about 50% egg mortality in recent years. It has also increased to the same level recently in Washington and is at the same level in Oregon. Samples from British Columbia and Alaska do not show these high levels. These studies are continuing under Sea Grant R/F-75 and are described in Wickham (1979a, b, c, 1980).

The second mechanism is a depression of equilibrium population level following an increase in individual growth rate (Botsford, 1981a). This mechanism may not apply to this fishery since high growth rates are observed only in San Francisco Bay (i.e., rather than a recent increase in growth rate, we may be seeing normal high growth rate in bays). This mechanism may apply to other fished species and is currently being tested in laboratory populations.

The economic portion of the study has focused on developing the inputs for a model to simulate the behavior of the Eureka crab fleet. Under the auspices of the California Sea Grant Marine Advisory Program, interviews were conducted with various fishermen both individually and in small group sessions to solicit information on fishing costs. Representative fixed and variable costs were estimated for a variety of activities for various vessel sizes operating in the Eureka crab, salmon, and albacore fisheries. Additional price and landings data for Eureka vessels were obtained from California Department of Fish and Game, Long Beach. Annual and monthly summaries of activities of crab vessels have been derived from the various data sources. The pounds, revenues, number of landings, and number of boats operating in various size classes are now available on a monthly basis. This represents an important data base on a portion of the California crab fleet.

This data is now being used to construct a simulation model of the behavior of the Eureka crab fleet. Various policy variables are included in the model, and the effect of management on the fleet will be studied by manipulating variables in the model. The primary concern is with the interdependence among the various fisheries brought about by economic forces.

The first step toward formulating policy for this fishery was to develop optimal policy results for the type of models that could describe a cycling fishery in which age structure and density-dependence are important. One of the results of this analysis was that pulse fishing was better than constant policy (Botsford, 1981b). While this result is somewhat theoretical and its practical implications require further elucidation, it is commensurate with the recent result showing that a pulse of high harvest during peaks of the cycles can stabilize the fishery (Botsford *et al.*, submitted). Although this is a provocative result and a potentially valuable management tool, its full ramifications on the fishery are still being evaluated. It appears, however, that this policy would not only stabilize the fishery if density-dependent recruitment were the cause of cycles, but also would improve returns if environmental fluctuations are driving the cycles.

Work on the predator worm is continuing under Sea Grant project R/F-75. We are engaged in further sampling, evaluation of the effect of real growth rates on cycles, further evaluation of environmental effects, and obtaining numerical fishery policy results.

The aquaculture portion of this project has involved updating economic paramaters in the lobster model and revising cost projections. Culture costs increased approximately 37% from 1976 to 1980 (Johnston and Botsford, 1980). We have also continued work on the monograph, *The Bioeconomics of Aquaculture: A Systems Approach.*

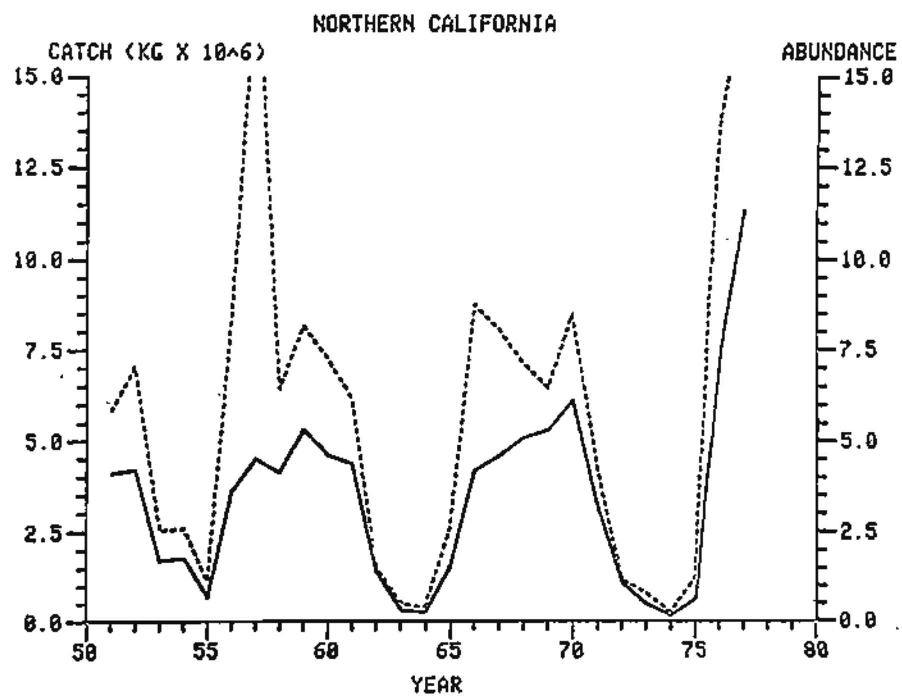


Figure 1. Results of analysis of environmental variables and fluctuations in effort in response to abundance.

Table 1

Levels of YOY in Older Crabs' Guts

Month	Depth	Number in Sample	Number in Guts
April	30 m	10	33
June	10 m	51	2
	20 m	12	4
	30 m	11	8
July	10 m	10	3
	20 m	6	16

Cooperating Organizations

California Department of Fish and Game
National Marine Fisheries Service

References

BOTSFORD, L. W. 1981. Optimal fishery policy for size-specific, density-dependent population models. J. Math. Biol 12:265-293.

BOTSFORD, L. W. 1981. The effects of increased individual growth rates on depressed population size. Am. Nat. 117(1):38-63.

BOTSFORD, L. W. In press. Comment on cycles in the northern California dungeness crab population. Can. J. Fish Aquat. Sci.

BOTSFORD, L. W., METHOT, R. D., AND JOHNSTON, W. E. Submitted. Catch-effort dynamics of the northern California dungeness crab fishery. Can. J. Fish. Aquat. Sci.

BOTSFORD, L. W. AND WICKHAM, D. E. 1978. Behavior of age-specific density-dependent models and the northern California dungeness crab fishery. J. Fish. Res. Bd. Can. 35:833-843.

JOHNSTON, W. E. AND BOTSFORD, L. W. 1980. Systems analysis for lobster aquaculture. In *Symposium on new development in utilization of heated effluent and recirculation systems for intensive aquaculture.* FAD/EIFAC, Stavanger, Norway.

METHOT, R. D. AND BOTSFORD, L. W. Submitted. Estimates of pre-season abundance in the California dungeness crab fisheries. Can. J. Fish. Aquat. Sci.

WICKHAM, D. E. 1979a. Predation by a nemertean *Carcinonemertes errans* on eggs of the dungeness crab, *Cancer magister.* Mar. Biol. 55:45-53.

WICKHAM, D. E. 1979b. The crab egg predator *Carcinonemertes errans* and population cycling and collapse in its host, the dungeness crab. Ph.D. thesis, University of California, Berkeley.

WICKHAM, D. E. 1979c. *Carcinonemertes errans* and the fouling and mortality of eggs of the dungeness crab. J. Fish. Res. Bd. Can. 36:1319-1324.

WICKHAM, D. E. 1980. Aspects of the life history of *Carcinonemertes errans* (Nemertea: Carcinonemertidae), an egg predator of the crab *Cancer magister.* Biol. Bull. 159:247-257.

Publications

BOTSFORD, L. W. 1981. Optimal fishery policy for size-specific, density-dependent population models. J. Math. Biol 12:265-293.

BOTSFORD, L. W. 1981. Optimal fishery policy for size-specific, density-dependent population models. Presented at the joint annual meeting of the Biometric Society (WNAR) and the Institute for Mathematical Statistics (WR), Victoria, B.C., June 1981.

BOTSFORD, L. W. In press. Comment on cycles in the northern California dungeness crab population. Can. J. Fish Aquat. Sci.

BOTSFORD, L. W. AND METHOT, R. D. 1981. The effects of environmental variability on California dungeness crab and salmon catch. Presented at the annual meeting of the American Fisheries Society, Albuquerque, New Mexico, September 1981.

BOTSFORD, L. W., METHOT, R. D., AND JOHNSTON, W. E. Submitted. Catch-effort dynamics of the northern California dungeness crab fishery. Can. J. Fish. Aqual. Sci.

METHOT, R. D. AND BOTSFORD, L. W. Submitted. Estimates of pre-season abundance in the California dungeness crab fisheries. Can. J. Fish. Aquat. Sci.

AN ECONOMIC ANALYSIS OF THE CALIFORNIA ABALONE FISHERY AND THE EXPERIMENTAL ENHANCEMENT PROGRAM .

University of California, Santa Barbara
R/F-53
1980-81

Robert T. Deacon

The commercial fishery for abalone in California has experienced several dramatic changes during the last 30 years. The commercial catch, which exceeded 5 million pounds in the mid 1950s, fell to less than 1.5 million pounds in the late 1970s. During the same period, the number of vessels licensed to operate in the fishery nearly tripled until a limited entry program reversed the trend in 1977. Exvessel prices, which had been relatively stable in real terms during the 1950s and early 1960s, almost doubled between 1967 and 1978. These patterns have been popularly attributed to a variety of factors, but principally to increased predation by sea otters and commercial overfishing. Concern over the latter possibility was reflected in certain regulatory policies such as changes in legal size limits and the introduction of a limited entry program in 1977. It also led to public interest in the study of resource enhancement measures such as the Experimental Abalone Enhancement Program proposed by Tegner (1977). In accordance with the above considerations, the present program of economic analysis was directed toward development of an economic model of the California abalone fishery. The development and application of this model was intended to serve three related goals: 1) to gain an understanding of the economic and biological factors that contributed to the observed trends in the industry (summarized above), 2) to provide a vehicle that would permit one to analyze economic aspects of public regulation of the fishery, and 3) to provide estimates of the likely benefits and costs of the proposed enhancement measures. The research involved in developing and estimating the economic model, as well as applications in which it has been employed to date, are summarized below.

The first component of the model is a demand function for abalone, a behavioral relationship between price, income, population, and other determining factors, and the demand for the commercial catch. The commercial fishery harvests five subspecies of abalones (reds, pinks, greens, blacks, and whites), and species-specific price data were available for only a few years of the study period. An analysis of relative prices of the subspecies for years in which price data were available indicated that the different varieties may be substituted; that is, relative prices remained essentially constant despite significant variations in the distribution of the catch among species. Given this constancy of relative price, it is theoretically appropriate to aggregate the catch (using estimated relative prices as weights for landings of individual subspecies), and to treat the resulting aggregate as a single product.

The total supply of abalones available to U.S. consumers is dominated by imports (of fresh and canned product), primarily from Mexico. Moreover, the close correlation between domestic exvessel prices and reported import prices (simple correlation exceeds .99) indicates that the two supply sources are close substitutes. Since the domestic exvessel price will, as a result, be strongly influenced by the availability of supplies from imported sources, it was necessary to estimate the supply elasticity of imports to the U.S. Treating the U.S. as a competitor in the international market for abalone, supply to the U.S. is the residual or excess supply from other producing nations. To estimate this excess supply, it was necessary to estimate world supply and demand functions for abalone products. Demand was expressed as a function of price, income, and population in the major consuming nation, Japan. Supply was treated as a function of current price and lagged catches. (All nominal variables were expressed in "real" Japanese yen.) The estimation routine utilized was developed by Fair (1972), and is essentially a simultaneous-equations technique that allows for the presence of lagged endogenous variables and an autocorrelated error structure. Although the import supply elasticity estimates obtained varied with the exact specification of supply and demand models estimated, all estimates exceeded 10.0. From this it follows that domestic price levels are virtually completely determined by conditions in international markets. This result is highly convenient in that it allows price to be treated as an exogenous or predetermined variable in subsequent analysis. It is also of interest in that it provides insight regarding the trends in U.S. prices observed since 1950. Between 1950 and 1967, both (inflation adjusted) U.S. prices and international prices showed only slight increases. This was, of course, also a period of relatively stable currency values. After 1967, the rapid rise in U.S. prices coincided almost precisely with the decline in the value of the U.S. dollar vis-à-vis the currencies of other consuming nations (particularly the Japanese yen). When U.S. prices are expressed in terms of the inflation-adjusted Japanese yen, they are seen to have remained virtually constant since 1967.

The second component of the model consists of a specification of the dynamic behavior of the stock. Although a traditional logistic approach was initially investigated, it was deemed inappropriate for analysis of this fishery, in which size selection is highly important. As an alternative, an age class or multiple cohort approach was pursued (Beverton and Holt, 1957, Ricker, 1975). Because the desired final product was a specification that could be used in empirical analysis, the standard theoretical development of the model was modified in certain respects. The stock, and all flows contributing to changes in the stock (recruitment, mortality, harvest) were specified in the numbers rather than mass. All of the flow prices were modeled in discrete (rather than continuous) time, and fishing and mortality were assumed to operate in a sequential (rather than simultaneous) fashion. The result is a recursive equation that expresses the change in the stock in terms of the annual harvest, recruitment, and a natural mortality rate. When iterated over time, it is possible to express the stock in any year as a function of a sequence of lagged catches and recruitments, where the lag coefficients form a declining geometric series. An analysis of available biological information regarding survivorship, growth, and fecundity among abalones indicated that, given the size limits in force during the sample period, recruitment could be considered to be independent of the level of commercial harvests. Hence, recruitment was assumed to be a (linear) function of measurable environmental variables alone. It should be noted that within this framework, both the natural survival rate and recruitment are parameters to be estimated.

The current commercial harvest was specified to be the product of the size of the stock and the fishing mortality rate. Fishing mortality is expressed as a nonlinear function of current fishing input levels and weather conditions. (The only input for which a consistent and complete series of data could be located was the number of licensed vessels.) The level of inputs involved in fishing was assumed to respond to product price, such cost factors as fuel prices and wage rates, and to fishing success as measured by catch per unit effort.

When these relationships are combined, the net result is a system of two simultaneous equations. The first expresses current catch as a function of current effort and the size of the stock. The second specifies effort as a function of price, costs, and fishing success. The catch equation is highly nonlinear in its arguments, but rather economical in terms of the number of parameters that need be estimated. Due to an absence of catch and effort statistics over an adequate sample period for estimation, or to a lack of knowledge regarding certain biological factors, empirical application of the model has been confined to the fishery for pink abalone. Estimation was accomplished by use of a nonlinear two-stage least-squares technique developed by Amemiya (1974). The nonlinear estimation routine converged rapidly and produced estimates that are plausible in sign and magnitude and highly significant in a statistical sense. Overall, the model was able to account for slightly more than 90% of the observed variation in the commercial catch during the postwar period.

The catch equation provided estimates of annual recruitment, the natural survival rate, the marginal productivity of fishing effort, and (indirectly) the fishing mortality rate and stock level in each year. In the case of natural mortality, it was possible to relate the estimates obtained from the model to those available from independent biological research. Here, the general level of agreement was quite close. The economic model yields estimates that were within 2-13% of biological estimates.

By using the estimates to simulate changes in the stock over time, it was possible to gain insight regarding the factors that contributed to declining catches during the postwar period. The reduction in catch and catch per unit effort experienced in the pink abalone fishery during the early 1950s appears to be attributable to the inevitable decline in accumulated stocks that must occur when a commercial fishery is introduced to a previously unexploited resource. (Commercial catches of pink abalone were first recorded in 1947.) The model indicates that by 1960, stocks of pink abalones had reached a rough equilibrium that was maintained (with minor fluctuations) throughout most of the following decade. Thus, the rather high commercial landings of pinks recorded during the 1960s appeared to be sustainable. According to the model, the size limit increase (from 6.0 to 6.25 inches maximum diameter) introduced in 1970 reduced effective recruitment to legal size by over 70%. Thus, the sharp declines in catch during the early 1970s are largely attributable to this policy change. Combining this finding with the result that the catch levels observed prior to the size limit increase were apparently sustainable, the policy change appears to have been ill-advised.

Parameter estimates from the model were also incorporated in a dynamic programming problem to compute optimum steady state levels of effort and yield under varying assumptions regarding prices, cost, interest rates, and the size limit in force. Using price cost and interest rate levels observed in 1975, and assuming that the initial size limit (6.0 inches) was restored, the indicated optimum level of effort was about 63% of that actually observed under unregulated (open access) conditions. The optimum was found to be quite sensitive to price and cost conditions, but relatively insensitive to differing interest rates (a result similar to that obtained by Hannesson (1974) in his study of the North Atlantic cod fishery). For a variety of reasons, including an absence of projected cost and price changes, the above findings are not regarded as conclusive or as a sufficient basis for policy recommendations. They do, however, illustrate the potential uses of the estimates obtained and of the general approach to fishery economics developed in this project.

Limitations of space do not permit the elaboration of further details of the analysis carried out during the completion of this project. Chief among these omitted topics are the estimation of mortality rates from age distribution data; the analysis of growth, mortality, and fecundity as they relate to possible stock-recruitment relationships; theoretical analysis of the relationship between fishing effort and fishing mortality; and the analysis of costs experienced during experimental abalone seeding and other enhancement efforts.

Cooperating Organizations
California Department of Fish and Game
National Marine Fisheries Service
Seafood Specialities, Inc.
University of Washington

References

AMEMIYA, T. 1974. The nonlinear two-stage least-squares estimator. Journal of Econometrics 2:105-110.

BEVERTON, R. J. H. AND HOLT, S. F. 1957. In *On the dynamics of exploited fish populations*. London. Her Majesty's Stationery Office.

DEACON, R. T. 1981. On the economics of fishery dynamics: an age class model of the California Abalone Fishery. Dept. of Economics, University of California, Santa Barbara.

FAIR, R. C. 1970. The estimation of simultaneous equation models with lagged endogenous variables and first order serially correlated errors. Econometrica 38:507-16.

HANNESSON, R. 1976. Fishery dynamics: a north Atlantic cod fishery. Canadian Journal of Economics 8:151-73.

RICKER, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Ottawa: Department of the Environment, Fisheries and Marine Service.

TEGNER, M., *et al.* 1977. The experimental abalone enhancement program. Institute of Marine Resources. La Jolla, California.

Publications

DEACON, R. T. 1980. The economics of the California abalone fishery and the experimental enhancement program. Presentation sponsored by California Marine Advisory Program, August 1980, Santa Barbara, California.

DEACON, R. T. 1981. On the economics of fishery dynamics: an age class model of the California Abalone Fishery. Dept. of Economics, University of California, Santa Barbara, California. Preliminary draft.

DEACON, R. T. 1981. On the economics of fishery dynamics: an age class model of California abalone fishery. Annual Conference of the Atlantic Economic Society, New York, October 1981.

DEACON, R. T. In prep. 1981. Economic aspects of the California abalone fishery. Monograph.

DEMOGRAPHIC ANALYSIS OF PORPOISE POPULATIONS SUBJECT TO TIME-VARYING TUNA-NET MORTALITY

University of California, San Diego
R/F-56
1980-81

Daniel Goodman

In the late 1950s the American tuna fleet in the eastern Pacific adopted purse seine gear as the most effective method of capturing yellow-fin tuna. During the first decade of this fishery, there were massive incidental porpoise kills. The tuna schools were specifically located by looking for porpoise, as the two school together, and the tuna school could, to an extent, actually be "herded" at some depth by herding the porpoise at the surface. When the porpoise were encircled in the net, along with the tuna, they often became entangled in the net and drowned or suffered other injuries.

In time, modifications were made to the gear, and net-handling techniques were developed that facilitated the release of porpoise before the final phase of drawing in the catch. While these improvements substantially reduced the incidental kill of porpoise, the populations of several species of porpoise had already been considerably reduced in the area of the fishery. Therefore, under authority of the Marine Mammal Protection Act, the status of these creatures became an important component of those factors considered in the regulation of the tuna fishery.

One important index to the status of the populations is their growth rate, the estimation of which became an object of concern within the responsible agency.

A population's growth rate is computed roughly as a difference between its birth rate and death rate, with certain corrections being made for the age composition of the population at any given time. For these porpoise, extensive data on reproductive status of females sampled from the kills provided information on age and frequency of reproduction, from which a birth rate can be computed.

There are two components to the death rate: the mortality owing to the incidental kill and the natural mortality. The mortality rate owing to the incidental kill is readily estimated from the reports of shipboard observers, but there are no direct data concerning natural mortality rates. To fill in this gap, we have undertaken an analysis of the age distributions reported in the kills, in an effort to deduce the mortality rate from the age structure.

The stable age distribution associated with a life table reflects the survival rates discounted by the growth rate of the population. If the population is in stable age distribution, graphical techniques may be employed to relate the population growth rate to partial information on the relative abundances and relative mortality rates of a few age classes. This would suffice for computing a natural mortality rate from the available data on porpoise, except that this population is not in stable age distribution, so the method, in its simplest form, does not apply.

Attainment of stable age distribution in a population requires that the effective birth rates and death rates be essentially constant for a prior period corresponding in duration to a few generations. The incidental mortality for the porpoise has varied by an order of magnitude in the recent past, and indeed this mortality factor only began to operate in the population a few generations ago, so the porpoise population cannot reasonably be assessed as if it were in stable age distribution. However, provided the fluctuations in incidental kill are the primary sources of variation in the dynamics of the porpoise population, we can correct for this variation, since we have a record of those fluctuations. Thus the mathematical key to our analysis is to reconstruct something like a stable age vector which incorporates the known effects of the time varying incidental kill.

We accomplish this through analysis of the following equation:

$$\underline{n}_{t+1} = A\underline{n}_t - \underline{h}_t$$

where $\underline{n}_t$ is the vector of abundances of individuals, age class by age class at time t, and A is the projection matrix (Leslie matrix) representing the time constant natural age specific rates of birth and death, and the vector $\underline{h}_t$ is the number of individuals killed, age class by age class, in year t. Interestingly, when this difference equation is projected forward to a final time t from an initial time o, the effects of the underlying natural rates and the effects of the time varying kill can partially be separated:

$$\underline{n}_t = A^t\underline{n}_o - \sum_{j=0}^{t-1} A^{(t-j-1)}\underline{h}_t$$

We note that the first term involves only the natural rates and the initial age distribution of the population, whereas the second term is a summation involving the natural rates and the sequence of kills. In our actual case, of course, the initial age distribution, which is to say the age composition of the porpoise population before the incidental kills began, is unknown, so its appearance in the formula adds to the number of things we would have to estimate. Fortunately, if t is not small, the expression $A^t\underline{n}_o$ converges to the vector representing the stable age distribution of the matrix A, regardless of the values in the initial population, so we may rewrite the equation in terms of the stable age distribution, and not trouble ourselves over our ignorance of the initial composition of the population. The second term in the equation consists simply of the record of kills, which is known, and elements of the natural rates — namely the birth components, which are known, and the natural mortality components, which we are trying to estimate. In this form, the equation can be thought of as an expression for the stable age distribution corrected for the effects of the history of kills.

This expression is a vector equation, so it really corresponds to several simple equations (essentially one equation for every age class in the population), and in fact it gives us sufficient equations to estimate the unknown natural mortality rate. This can be approached as a curve-fitting exercise in a number of ways, such as comparing the final observed age distribution in the population (not the age distribution of the kill) with a computed age distribution, or comparing the sequence of age distributions of the kill with a computed sequence based on an assumption that the age selectivity of the kill has not changed (or if it has changed, by incorporating that change into the equations). The stability of the curve-fitting operation rests on the above convergence property, which reduces the number of unknowns in the system of equations, by removing the influence of the unknown initial age distribution.

We have designed a number of such curve-fitting programs for a variety of data configurations, and have written the computer codes for actually carrying out the calculations with some specific data sets. The method is a powerful extension of the conventional analysis of age distributions which are presumed stable, and it will doubtless see many more applications, for it is common that the historical data on a harvested population consist primarily of a record of the harvests, and that is precisely the information our method uses.

We have presented the theory and applications of the method at several workshops and symposia, and have prepared manuscripts for journal publication (in addition to symposium proceedings). The Sea Grant funding of this project has now run its course, and we look back with considerable satisfaction at our accomplishments. The mathematical convergence property proved to be of such fundamental importance that we were able to use it as the basis for a theoretical analysis of a related problem (optimal life histories, and parameter estimation, where birth rates vary randomly in time) which was pursued with National Science Foundation funding, and which has resulted in two papers (one in press in a journal and one to appear in a symposium volume). And finally, the actual estimation of mortality rates for the porpoise population, which is of greatest concern regarding regulation of the fishery, will be carried out under a National Marine Fisheries Service contract next year using the latest data provided by the agency.

Cooperating Organizations
National Marine Fisheries Service

Publications

BARLOW, J. P. Submitted. 1981. Age structure and the dynamics of the Kaibab deer herd. J. Wildl. Mng.

BARLOW, J. P. 1981. Nonlinear approaches to mortality rate estimates. Ph.D. dissertation chapter.

BARLOW, J. P. 1981. Reproductive seasonality and its implications in measuring vital rates. Invited paper presented at NMFS Cetacean Reproduction Workshop, 1981.

GOODMAN, D. 1979. Calculating vital rates from spotted porpoise age distributions. NMFS, Status of the Porpoise Stocks Workshop, Document 51.

GOODMAN, D. 1979. On the interpretation of age distributions. IUCN & WWF Workshop on the Biology and Management of Northwest Atlantic Harp Seals. Working Paper 7.

GOODMAN, D. 1980. Regulating kills of porpoise incidental to the purse seine tuna fishery. Report to NOAA.

GOODMAN, D. In press. 1981. Risk spreading as an adaptive strategy in iteroparous life histories. Theor. Pop. Biol.

ASSESSMENT OF AGING TECHNIQUES AND THEIR APPLICATION TO ELASMOBRANCH FISHERIES

Moss Landing Marine Laboratories
R/F-57
1980-81

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 are 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. The usual means of aging fishes — by examinging scales, otoliths, or bones — are not applicable to elasmobranchs, and there has been no other method for easily determining their age. (Stevens, 1975; Holden, 1977). The evidence that does exist indicates that growth rates are slow and time to sexual maturity is very long, estimated at about 9 years for *Galeorhinus zyopterus* (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). Since stock and recruitment are more closely related in elasmobranchs than in teleostean fishes, fishing premature fish can quickly deplete populations. 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 tested aging techniques using vertebrae collected from common Californian elasmobranchs to determine which techniques were applicable to specific species and which had the widest applicability and highest accuracy. In the second year, we applied these techniques to as many commercial and potentially commercial elasmobranchs as possible from California waters.

We have spent over 200 days collecting more than 1,100 specimens from 23 species of sharks, skates, and rays. 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 numerous methods of exposing the rings for counting, including silver nitrate impregnation, radiography, formic acid etching, oil clearing, and several types of staining procedures. Different ring counting methods were suitable for different species, but no one technique could be used for all (table 1). For example, both the silver nitrate and x-radiography techniques delineated circuli well on vertebrae of the bonito shark, but only silver nitrate worked consistently well with the leopard shark. We have prepared vertebrae and counted their rings in 684 individuals of 14 species of elasmobranchs, including 191 bat rays, 131 leopard sharks, 88 smoothhounds, 85 skates, 57 thresher sharks, 41 angel sharks, and 26 bonito sharks (table 1). In addition, we have collected vertebrae from eight other species, but were not able to process them or test the various techniques on their centra.

We have produced reliable growth curves for five species commonly available in central California (bat ray, leopard shark, gray and brown smoothhounds, and blue shark) and preliminary curves for three others (thresher shark, bonito shark, angel shark). For example, using silver nitrate and formic acid techniques, we determined that the leopard shark lives at least 14 years and its growth curve closely approximates the von Bertallanfy growth model (figure 1).

We have been able to use some limited age verification methods such as size and number of rings in centra of newborn individuals, size frequencies of young age classes, seasonal changes in the dimensions and clarity of edge circuli, and tag-recapture size information on three of the species for which growth curves were produced. For these species, the bands appear to be annual, but such verification is still needed for the majority of the many elasmobranch species with realized or potential commercial importance.

In order to correlate growth data with maturity, we have developed qualitative, descriptive techniques to assess reproductive state and more quantitative techniques to evaluate features such as fecundity in females and sperm maturation in males. We have applied these data on reproduction to those five species for which we have reliable growth curves. In general our results agree with those found for other elasmobranchs (Steven, 1936; Ketchen, 1972, 1975; Holden, 1973, 1974, 1977; Jones and Geen, 1977a, b). Growth is relatively slow, time to sexual maturity relatively long, first reproduction occurs relatively late in life, and fecundity is low. For example, the leopard shark does not reproduce for the first time until the tenth year for females and the eighth year for males (see figure 1). The female has a gestation period of approximately 1 year and has up to 36 offspring per birth. Similarly, bat rays live at least 23 years, males first mature at 3 years and females at 5 years, and females produce an average of four offspring after a year-long gestation period.

In summary, we have succeeded in developing techniques for aging elasmobranchs, have applied and tested them for numerous species, and hope that our methodology will allow other species of sharks, skates, and rays to be aged. The resulting information on age composition, growth, and size-specific reproductive habits will increase the management capability for these emerging resources.

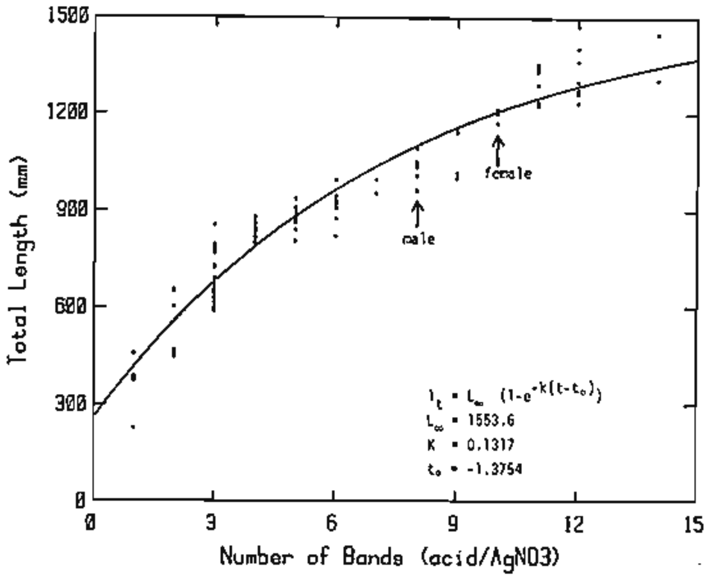


Figure 1. Von Bertalanffy growth curve derived from silver nitrate treated circuli (bands) of 131 male and female leopard shards (*Triakis semifasciata*) from central California. Estimated size and age of first reproduction are indicated for males and females.

Table 1

Summary of Collection and Processing Activities from 1979 to 1981*

		Technique				
Common Name	Scientific Name	Silver Nitrate	X-Radiography	Oil Clearing	Number Sampled	Number Aged
Bat ray	*Myliobatis californica*	-	+	+	191	191
Leopard shark	*Triakis semifasciata*	+	-	?	136	131
Brown smoothhound	*Mustelus henlei*	+	+	?	50	50
Gray smoothhound	*Mustelus californicus*	+	+	?	38	38
Common thresher	*Alopias vulpinus*	+	+	+	57	57
Bonito shark	*Isurus oxyrinchus*	+	+	+	23	23
Blue shark	*Prionace glauca*	+	-	+	26	26
Pacific angel shark	*Squatina californica*	+	+	?	56	41
Soupfin shark	*Galeorhinus zyopterus*	+	?	?	70	0
Longnose skate	*Raja rhina*	-	-	+	196	35
Big skate	*Raja binoculata*	-	-	+	188	50
Spiny dogfish	*Squalus acanthias*	-	-	?	70	40
Basking shark	*Cetorhinus maximus*	+	+	+	2	1
White shark	*Carcharodon carcharias*	+	+	?	9	1
					1,112	684
8 additional species		?	?	?	40	0
Total					1,152	684

* Table shows the number of each species of elasmobranch collected and aged and the relative effectiveness of three techniques for clarifying circuli in vertebral centra. These techniques were evaluated as those which worked well (+), worked poorly (-), or were not tried (?).

Cooperating Organizations
Cabrillo Museum, Long Beach
California Academy of Sciences
California Department of Fish and Game
National Marine Fisheries Service
Natural History Museum of Los Angeles County
Santa Barbara Museum of Natural History
Sea Grant Marine Advisory Service
Several southern California fishermen's associations
Steinhart Aquarium
Tiburon Center for Environmental Studies
U.S. Fish and Wildlife Service

References

BYERS, R. B. 1940. The California shark fishery. Calif. Fish and Game 26(1):23-38.

FREY, H. W. 1971. California's living marine resources and their utilization. Publication 1-180. Calif. Dept. of Fish and Game.

HART, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can. Bull. 180:1-740.

HOLDEN, M. J. 1973. Are long-term sustainable fisheries for elasmobranchs possible? J. du Conseil, Rapports et Proces-Verbaux Reun. Cons. Int. Explor. Mer. 164:360-367.

HOLDEN, M. J. 1974. Problems in the rational exploitation of elasmobranch populations and some suggested solutions. In *Sea Fisheries Research*, F. R. Harden-Jones, ed. John Wiley and Sons, New York.

HOLDEN, M. J. 1977. Elasmobranchs. In *Fish Population Dynamics*, J. A. Gulland, ed. John Wiley and Sons, New York.

HOLDEN, M. J. AND VINCE, M. R. 1973. Age validation studies on the centra of *Raja clavata* using tetracycline. J. du Conseil 35(1):13-17.

JONES, B. C. AND GEEN, G. H. 1977a. Age determination of an elasmobranch (*Squalus acanthias*) by X-ray spectrometry. J. Fish Res. Board Can. 34:44-48.

JONES, B. C. AND GEEN, G. H. 1977b. Reproduction and embryonic development of spiny dogfish (*Squalus acanthias*) in the Strait of Georgia, British Columbia. J. Fish Res. Board Can. 34:1286-1292.

KETCHEN, K. S. 1972. Size at maturity, fecundity and embryonic growth of the spiny dogfish (*Squalus acanthias*) in British Columbia waters. J. Fish. Res. Board Can. 29:1717-1723.

KETCHEN, K. S. 1975. Age and growth of dogfish *Squalus acanthias* in British Columbia waters. J. Fish Res. Board Can. 32:43-59.

STEVEN, G. A. 1936. Migrations and growth of the thornback ray (*Raja clavata* L.). J. Mar. Biol. Assoc. U.K. 20:605-614.

STEVENS, J. D. 1975. Vertebral rings as a means of age determination in the blue shark (*Prionace glauca* L.). J. Mar. Biol. Assoc. U.K. 55:657-665.

Publications

CAILLIET, G. M., KUSHER, D., MARTIN, L., AND WOLF, P. In press. 1981. A review of several methods for aging elasmobranchs. Cal-Neva Wildlife Transactions, Am. Fish Soc.

KUSHER, D. 1981. Studies on age, growth and first reproduction of the leopard shark (*Triakis semifasciata*). Presented at 61st annual meeting, American Society of Ichthyologists and Herpetologists, Oregon State University, Corvallis, June 1981.

MARTIN, L. K. 1981. Age, growth and reproduction in the bat ray, *Myliobatis californica*, in Elkhorn Slough, California. Dept. of Zoology, University of Melbourne, Australia, July 1981.

MARTIN, L. K. 1981. Life history, abundance, distribution and feeding habits for commercially important sharks. University of California Sea Grant Alternative Fisheries Workshops, Fort Bragg and Eureka, California, November 1981.

MARTIN, L. K. 1981. The growth and reproduction of the bat ray, *Myliobatis californica*, Gill. M. A. thesis, San Jose State University.

MULTIPLE SPECIES UTILIZATION OF THE HERRING EGGS-ON-SEAWEED FISHERY

Stanford University
R/F-58
1980-81

Isabella A. Abbott and Judith E. Hansen

The red alga *Gracilaria* sp. is one of the primary sources of agar. This colloid is used by food industries for its unique gelling properties and as the base for microbiological and tissue culture media. The foods and health-related fields and research institutes require predictable sources of good to high quality agar. Currently, the majority of agar used in the United States is imported. The commercial agar blends are composed of extracts from many agarophyte species (and sometimes carrageenophytes) collected from natural populations worldwide and at different times of the year. This haphazard seaweed gathering results in importation of agar with unpredictable qualities, a significant problem especially to health fields which rely on agar-based media for diagnostic purposes. A solution is mariculture of stable, domestic agarweed species — a complex, biological problem.

Gracilaria and other seaweeds (*Laminaria, Macrocystis*, etc.) provide the basis for yet another industry — the herring eggs-on-seaweed fishery of the U.S. west coast. This small, but lucrative fishery depends upon large, stable, "preferred" seaweed crops in the herring spawning grounds during the winter spawning season. The herring eggs-on-seaweed is harvested, salt-cured, and exported to Japan where it is considered a delicacy. It retails for $2.50-25.00 per pound depending upon the seaweed and the number of egg layers on it.

These seemingly diverse areas of endeavor are united by a common need; both require a stable and predictable seaweed source. The overall goal here is to explore the potential for mariculture of a high quality agarophyte which is also suitable as a substratum for the herring eggs-on-seaweed fishery. *Gracilaria* has both characteristics. The problem lies in biological timing. The *Gracilaria* crop must be cultivated and located within the herring spawning grounds at the proper time; thereafter, it can be harvested as an agar source. The approach to this problem involved three areas of study: field, mariculture, and laboratory.

Gracilaria Population Field Study

Elkhorn Slough, Monterey Bay, California was the site for *Gracilaria* and herring field studies. A *Gracilaria* population was randomly sampled seasonally for a 2-year period to determine 1) seasonal changes in standing crop, 2) growth rates following harvesting, and 3) 3-month regrowth following seasonal harvests. The initial *Gracilaria* standing crop ($\bar{X}$ = 3170 ± 350 gFW/.5 m^2) was devastated (to 3 ± 1 gFW/.5 m^2) by severe water motion associated with winter storm activity. Repopulation was slow and peak crops to date (1 Oct. 1981) have reached only 12% of the original biomass. The reduced populations show an annual pattern characterized by peak crops in autumn-winter followed by significant crop reductions to low points in spring. Harvesting by cutting the initial crop and plots at the beginning and end of 3-month periods had no significant effect on regrowth; biomass levels were similar to controls (figure 1).

Agar extracted from control biomass samples had high gel strength throughout the studies (700-1200 gm/cm^2; Guiseley, Marine Colloids of FMC).

Herring Eggs-On-*Gracilaria*

Vegetation maps for Elkhorn Slough were prepared prior to herring spawning assessments during the winters of 1979-80 and 1980-81. Methods developed during California Department of Fish and Game herring studies were used (Miller and Schmidtke, 1956; Hardwick, 1973). Herring spawned between December and March in different locations during the 2-year study. The estimated spawning biomass was 2-4 short tons (1979-80) and 0.2-1 ton (1980-81). Estimations were made using two independent techniques developed by Haegele *et al.*, (1979) and Spratt (in press). The herring eggs-on-seaweed in Elkhorn Slough was considered light to very light by commercial standards. Measured *Gracilaria* biomass and estimated spawning herring biomass were correlated.

Mariculture Study

Native *Gracilaria* from Elkhorn Slough was used as "seed material" for cultivation experiments in a 10 x 30 m raceway. A technique was developed for the vegetative propagation of *Gracilaria* on monolines. Thallus fragments were bundled together using transparent polypropylene ties and attached to the monolines. Growth rates (10-20% per day) vary with bundle stocking density (10-500 g).

Prior to the 1980-81 winter herring spawning season, a monoline structure was located within the spawning grounds in San Francisco Bay. A *Gracilaria* crop was planted and cultivated on the monolines to provide a substratum for spawning herring. The crop was spawned on at commercial levels twice during the season. The primary herring eggs-on-seaweed fisherman for 1980-81 (San Francisco Bay), T. Ichinose, was given hands-on instruction in using this successful mariculture technique for future seasons.

Laboratory Studies

The effects of seawater oxygen (O_2) (figure 2) and carbon (C) (figure 3) levels on *Gracilaria* photosynthetic rates were determined. Initially, an oxygen probe (Rank Bros., England) was used that gave low and variable results. A modified winkler technique (accuracy: 0.02 ml O_2/l) (Hansen, 1980) proved to be more appropriate for this alga. Based on preliminary experiments it is suspected that *Gracilaria* spp. excrete either volatile or low molecular weight sulfur compounds that interfere with the oxygen probe membrane (W. Fenical, personal communication). Experiments were carried out using 700 μE·m^2·sec^{-2}, 15 ± 2°C, 0.5 to 1.0 h duration with filtered seawater and a thallus weight-to-chamber volume (g/l) of 0.2-0.6 g wet wt/l.

Experimental plants were strains selected from and cultivated in Elkhorn Slough, California.

Net photosynthetic rates for *Gracilaria* in seawater with oxygen concentrations between 2.8-3.9 ml/l (19.6 ± 2.0 ml O_2/gDW/hr) were significantly greater ($p = .02$) than rates measured with either low O_2 ($\leq$1.7 ml/l) or higher O_2 levels (4.0-5.8 ml/l) in seawater. However, high photosynthetic rates were also measured for plants in supersaturated seawater (5.2-6.9 ml O_2/l). It has been reported that photosynthesis of some algae is inhibited by high levels of O_2 in seawater (Downton *et al.*, 1976; Littler, 1979). Results from this study indicate that such a relationship is questionable for *Gracilaria* (Elkhorn Slough type).

Photosynthetic rates for *Gracilaria* in seawater enriched with 2 mM ($p = .005$) and 5 mM C ($p = .02$) were significantly greater than rates in ambient seawater (approx. 2.2 mM C). Higher levels of C enrichment had no stimulatory effect on net photosynthesis (figure 3).

Gracilaria from Elkhorn Slough, Moss Landing Harbor, and Agassiz Beach (Hopkins Marine Station), California were grown in flow-through seawater tanks in salinities from 20-35 parts per thousand to determine the effects of salinity on thallus morphology and growth. During the three replicate, 1-month experiments, no morphological changes were observed. Plants from Elkhorn Slough grew significantly faster at ambient salinity, whereas salinity had no consistent effect on plants from the other populations tested.

Conclusions

Gracilaria from Elkhorn Slough, Monterey Bay, California is a good source of agar. There is a consistent annual pattern in standing crop of this alga, though the magnitude from year to year varies. Entire populations can be devastated by severe winter storms. Harvesting the standing crops has little effect on growth or re-establishment of the population studied.

Gracilaria is the primary spawning substratum for herring in the slough. Herring eggs-on-seaweed in the slough was light ($\leq$4 tons; 1979-80) to very light ($\leq$1 ton; 1980-81) by commercial standards and varied in location during the 2-year study.

Mariculture of *Gracilaria* on monoline structures was successfully developed and tested. Cultivated crops on monolines provided substrates for two commercially harvestable herring eggs-on-seaweed crops in San Francisco Bay (1980-81). The technique is flexible and cultivation structures and seaweed crops can be moved from bay to bay for various purposes.

Gracilaria photosynthetic rate is most appropriately measured using the Winkler technique. Oxygen probes can give ambiguous results probably due to interaction with products excreted by stressed thalli in certain seasons.

Net photosynthesis of *Gracilaria* is not significantly inhibited by high seawater O_2 levels. *Gracilaria* (Elkhorn Slough type) is carbon limited in unenriched seawater. However, enrichments above 5 mM have no stimulatory effect.

Salinity (20-35 parts per thousand) has no effect on *Gracilaria* morphology. Growth of plants from Elkhorn Slough was depressed at 25 parts per thousand.

It is concluded from this 2-year study that vegetative cultivation of *Gracilaria* is feasible and can be successfully used to provide a substratum for extending the herring eggs-on-seaweed fishery. Agar is consistently of good quality; however, natural populations are unstable. Physiological results indicate that *Gracilaria* (Elkhorn Slough type) production can be enhanced by manipulation of cultivation regime.

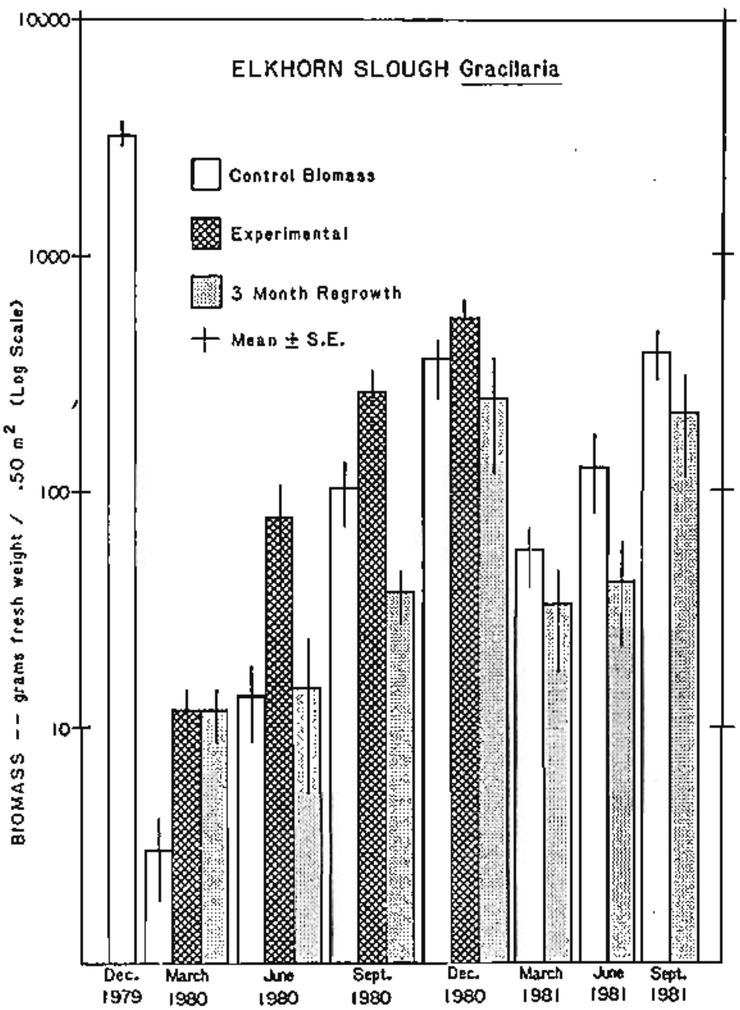


Figure 1. Elkhorn Slough *Gracilaria* biomass. Controls = untreated population. Experimental = biomass regrowth (cumulative) following a one-time, Dec. 1979 harvest. 3-Month regrowth = biomass accumulated in discrete 3-month periods.

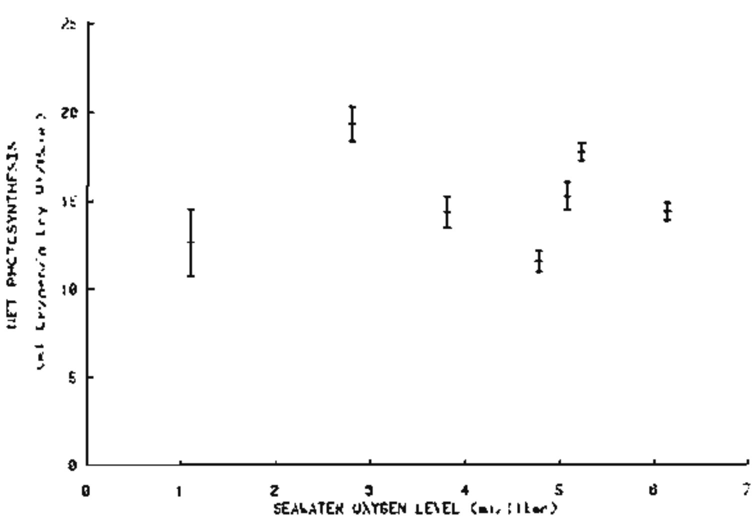


Figure 2. *Gracilaria* net photosynthesis versus seawater oxygen concentration.

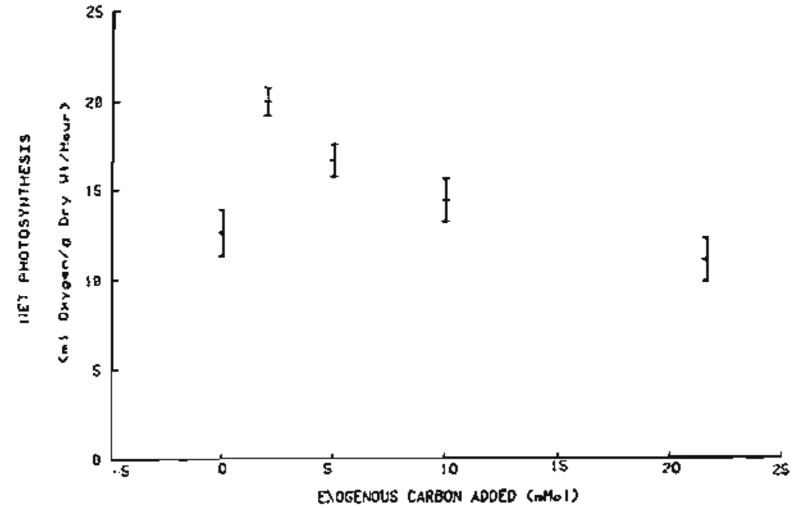


Figure 3. *Gracilaria* net photosynthesis versus seawater carbon concentration.

Cooperating Organizations

California Department of Fish and Game
Marine Colloids of FMC
Soil Control Lab/Marine Bioassay Laboratory

References

Downton, W., Bishop, D., Larkum, A., and Osmond, C. 1976. Oxygen inhibition of photosynthetic oxygen evolution in marine plants. Australian J. Plant Physiol. 3:73-79.

Haegele, C., Miller, D., Humphreys, R., and Hourston, A. 1979. Assessment of 1978 herring spawning in the French Creek and Qualicum herring sections, using new egg determination procedures. Tech. Rep. #896. Can. Fish & Mar. Ser. pp. 1-43.

Hansen, J. 1980. Physiological considerations in the mariculture of red algae. In *Pacific seaweed aquaculture*, I. A. Abbott, M. S. Foster, and L. F. Eklund, eds. California Sea Grant College Program, La Jolla, California. pp. 80-92.

Hansen, J. In prep. Photosynthesis of red algae in air and water.

Hardwick, J. 1973. Biomass estimates of spawning herring, *Clupea harengus pallasi*, herring eggs and associated vegetation in Tomales Bay. Calif. Fish & Game 59:36-61.

Littler, M. 1979. The effects of bottle volume, thallus weight, oxygen saturation levels and water movement on apparent photosynthetic rates in marine algae. Aquatic Botany 7:21-34.

Miller, D. J. and Schmidtke, J. 1956. Report on the distribution and abundance of Pacific herring (*Clupea pallasi*) along the coast of central and southern California. Calif. Fish & Game 43:163-87.

Spratt, J. In press. The Pacific herring (*Clupea harengus pallasi*) in California. Fish Bull. Calif. Fish & Game.

Publications

Abbott, I. A. 1980. Seasonal population biology of some carrageenophytes and agarophytes. In *Pacific seaweed aquaculture*, I. A. Abbott, M. S. Foster, and L. F. Eklund, eds. California Sea Grant College Program, La Jolla, California. pp. 45-54.

Abbott, I. A. and Hoyle, M. In prep. The common intertidal species of *Gracilaria* (Rhodophyta) in California.

Chapman, F. A. In prep. Carrageenan and agar produced during decomposition of red seaweeds.

Hansen, J. E. 1980. Physiological considerations in the mariculture of red algae. In *Pacific seaweed aquaculture*, I. A. Abbott, M. S. Foster, and L. F. Eklund, eds. California Sea Grant College Program, La Jolla, California. pp. 80-82; 190-92.

Hansen, J. E. 1981. New approaches to algal aquaculture: Physiology and strain selection, the keys to *Gracilaria* and *Gelidium* mariculture. Western Society of Naturalists Symposium, Santa Barbara, California. (Abstract).

Hansen, J. E., Packard, J. E., and Doyle, W. T. 1981. Mariculture of red seaweeds. Report No. T-CSGCP-002. California Sea Grant College Program, La Jolla, CA.

Lineback, D. 1980. Herring egg harvest at Elkhorn Slough. Science Notes. University of California, Santa Cruz, Vol. 7.

Phillips, R., Hansen, J., and Hardwick, J. In prep. Herring eggs-on-seaweed in Elkhorn Slough, California. Fish and Game Bull.

Phillips, R. and Hansen, J. In prep. Monoline cultivation of *Gracilaria* — Design. Fish & Game Tech. Reports.

ECONOMICS OF MULTIPURPOSE FISHING VESSELS: ASSESSMENT AND POLICY

University of California, Santa Cruz
R/F-61
1980-81

Suzanne Holt

This 2-year project's overall goal is to examine, theoretically and empirically, the behavior of multipurpose fishing vessels with respect to effort and investment decisions, and to draw implications for appropriate multipurpose fisheries management policy. In the first year, the project aimed at 1) developing theoretical models of effort and investment decisions, 2) deriving policy implications from the theory, and 3) conducting a preliminary investigation of the data for testing these models.

The project was timed to coincide with a National Marine Fisheries Service (NMFS) contract collecting effort and investment data by fishery from a sample of 385 west coast multipurpose vessels. NMFS agreed to make data available to this project for analysis and testing of the models.

This project cooperated with the contractors in the selection of variables and the design of the survey instrument. Unfortunately, the NMFS contract suffered setbacks in data collection and processing. These setbacks forced some reordering of the goals and tasks of both years of the project.

Specifically, the primary and unexpected task of the first year became data cleanup — the correction of extensive errors in transferring data from the questionnaires to keypunched cards, both keypunching errors and insufficient vessel data disaggregation by fishery. Until it could be assured that model testing would be possible, it was unreasonable to devote substantial time to model building. The data cleanup was completed at the end of 1980, with a complete data file prepared for this project and for NMFS.

In addition, the foundations for the effort and investment models were laid. The models generally assumed declining stock abundance, sequentially available stocks, constraints on the physical length of each season, and the absence of fleet quotas.

In the final year, the project has aimed at 1) refining theoretical models of effort and investment decisions, 2) deriving policy implications for successful fisheries management from these models, 3) evaluating the reliability of available data for testing the models, and 4) testing the models when reliable data were available.

After the project spent much of its first year cleaning up the data collected under the NMFS contract, it became clear that the data were unreliable. They could not be expected to present an accurate sample of multipurpose vessels because the original interviewers were unfamiliar with fishing and with information they received, and they had failed to collect sufficient fisheries-specific effort and investment data. Consequently the bulk of the second year was devoted to modeling and policy implications.

Three papers were written. "How Severe Can Fisheries Management Be?: The Limits of Capital Stuffing" was delivered at the Western Economic Association annual meeting in San Francisco, California July 4, 1981. "Inefficiencies in Fisheries: A Closer Look at Open Access and Mismanagement" is forthcoming in *Land Economics*. "Multipurpose Fishing Behavior under Open Access and License Limitation" is forthcoming in the *Canadian Journal of Fisheries and Aquatic Sciences*. "Heterogeneity in Multipurpose Fishing" is in progress.

The modeling and policy results discussed in the papers are to some extent counterintuitive. The results include the following: 1) in fisheries where stock abundance varies over the season, vessels may be of either too large or too small a scale, regardless of the kind of management policies chosen; 2) it may be practically impossible to determine the optimal vessel scale independent of management policies chosen; 3) gear and capacity restrictions generally disfavored by economists may be among the best practical management policies; 4) poorly regulated vessels will fish too little on more profitable stocks in a multipurpose fishery, and either too much or too little on less profitable stocks; 5) the appropriate management of multipurpose fisheries requires sufficient fleet reduction so that vessels fish the more profitable stock its entire season; 6) there may be too little idle fishing capacity available for the less profitable stocks; 7) license limitation may adversely affect less profitable stocks; 8) when vessel characteristics differ, unregulated fleets may be multipurpose when they should be species-specific; 9) unregulated multipurpose fleets can be approximately optimal under certain cost conditions; and 10) cost-effective management may involve discrimination against certain kinds of vessels.

Cooperating Organizations
National Marine Fisheries Service

Publications

HOLT, S. 1981. How severe can fisheries mismanagement be?: the limits of capital stuffing. Presented at the Western Economic Association Annual Meeting, San Francisco, California, July 1981.

HOLT, S. In prep. 1982. Heterogeneity in multipurpose fishing.

HOLT, S. In press. 1982. Inefficiencies in fisheries: a closer look at open access and mismanagement. In *Land Economics*.

HOLT, S. In press. 1982. Multipurpose fishing behavior under open access and license limitation. Canadian Journal of Fisheries and Aquatic Sciences.

A NEW METHOD FOR ESTIMATING THE ENERGY AVAILABLE TO FISHERIES

University of California, San Diego
Institute of Marine Resources
R/F-62
1980-82

Michael M. Mullin and Daniel Goodman

The project we are engaged in consists primarily of comparing two techniques for estimating the production of zooplankton, which constitute the primary source of food for fish. The two techniques we set out to compare were cohort analysis and the "weight-dependent" technique (a new method). Both of these techniques require certain data in order to be used. In an experiment conducted this year in the Scripps Institution of Oceanography deep tank, we obtained data and samples from which both techniques can be used.

Cohort Analysis

The production of a species of zooplankton, according to cohort analysis, is defined according to the general equation

$$P = \sum_{i=N2}^{adult} g_i \bar{B}_i \qquad (1)$$

where P is the production rate ($mg\ C \cdot m^{-2} h^{-1}$), g_i is the weight-specific growth rate (day^{-1}), and $\bar{B}_i$ is the biomass of the stage of copepod (between stage N2 —nauplius 2- and adult), corrected for mortality, $-M_i$.

The weight-specific growth rate, g_i, is obtained from a regression of the natural log of body weight, ln $\bar{W}_i$, on the development time, DT_i i'th stage according to the equation

$$\ln \bar{W}_i = \ln c + g_i\, DT_i \qquad (2)$$

where c is a constant (the intercept of the regression), g_i is the weight-specific growth rate (the slope of the regression), and DT_i is the development time of stage i, which is calculated from time-frequency distributions of the stages. Following the calculation of development times of stages, one calculates the mortality, $-M_i$, of each stage. One can then determine the value of the mortality-corrected biomass of a state i on a given sampling day from the equation

$$\bar{B}_i = \frac{N_i\, \bar{W}_i \left[e^{(g_i - M_i)} - 1\right]}{g_i - M_i} \qquad (3)$$

where N_i is the abundance of stage i (numbers/m^2 or numbers/m^3) on the sampling date. By substituting into equation 1, one can then calculate the production.

Essentially, the data required for this technique is

– N_i, the abundance of the stage on a given sampling day, and

– $\bar{W}_i$, the weight of an individual of that stage.

Weight-dependent Method

The expression for production, according to this technique, is

$$P = \sum_{i=1}^{I} N_i \left[a\ b\ C\ \bar{W}_i^n - k\ \bar{W}_i^m\right] \qquad (4)$$

where a, b, n, k, and m are empirically-determined constants (already known), N and $\bar{W}$ are as already defined, and C is the food concentration, in terms of carbon.

Essentially, this technique requires the same data as the cohort analysis technique, except that it also requires an estimate of the food concentration.

Results to Date

In the deep-tank experiment conducted earlier this year, we obtained all the samples necessary to calculate production according to both techniques given above. We have used several different types of analyses to estimate the concentration of food. Details on all sample analysis, and progress in the analysis, are given below.

Copepod abundance. A total of approximately 200 samples have been completely analyzed for the enumeration and identification of the 12 developmental stages of *Calanus pacificus* population collected during the deep-tank experiment. These samples were collected at 36-hour intervals as planned. From these, we have already calculated the development times of all stages in all three generations (necessary for cohort analysis).

Copepod weights. These were calculated from a regression of cephalothorax length on body weight obtained from animals which have been prepared for weighing. Body weight in a given sample was estimated from measurements of cephalothorax length.

Food concentration. Electronic particle counts have been completed (a total of more than 200 samples), and the data has been completely analyzed. An example of the data is shown in figure 1 and table 1.

A total of more than 200 chlorophyll-a concentration samples (the entire experiment) have been analyzed.

The analysis of the samples collected for species identification and phytoplankton enumeration was begun by Dr. Huntley and continued by Jonathan Trent, our Sea Grant trainee.

Temperature. All temperature measurements were taken during the deep-tank experiment, and this data set is complete.

Discussion

We have had two unexpected occurrences associated with this project, both of them welcome. We obtained some very valuable information on the vertical migration behavior of *Calanus pacificus* and how this behavior is related to the ontogeny of the species. We invited Mr. Kenneth Richter, a graduate student at SIO, to sample the deep-tank experiment with his high frequency sonar equipment, which remotely senses the abundances and locations of zooplankton in the water column. The data which Mr. Richter collected will appear in his Ph.D. dissertation.

The major results of our 60-day experiment in the Scripps Institution of Oceanography deep tank, in which we compared the estimation of zooplankton production by a) cohort analysis and b) the weight-dependent method, are summarized in figures 2 and 3. Figure 2 shows the total production in the deep tank (mg C/day) versus time (measurements made at 36-hour intervals) using the cohort analysis approach (solid line) and the weight-dependent approach (dotted line). On the whole, the agreement is quite good, as shown by a Bartlett's least square regression (figure 3, $r^2 = 0.68$). However, some subtleties which give rise to a nonperfect correlation are worthy of note; these will be discussed in detail in a paper now in preparation.

Our results on vertical migration are discussed fully in Huntley and Brooks (1982). Our results on selective feeding are fully discussed in Huntley *et al.* (submitted manuscript).

Table 1

Example of the Electronic Particle Count Data from the Deep-tank Experiment*

Sample:
May 8, 1981 0.2 m 1000 h Replicate 1
Volume counted (ml): .5
Time counted (sec): 49.4
Flow rate (ml/sec): 1.01214574899E-02
Total counted: 154883
Total counted (per ml): 309766.000001
Total volume (cubic millimeters/liter): 4.61002893183
Total carbon (micrograms/liter): 874.215951937

Channel	Percent Volumes	Correct Percent Volumes	Numbers (Per ml)	Volumes (Cubic mm Per Liter)	Carbon (UG Per Liter)	Percent Carbon
1	0.0	0.00	0.0	0.0000	0.00	0.00
2	0.0	0.00	0.0	0.0000	0.00	0.00
3	1.5	1.58	98405.5	.0729	40.17	4.59
4	1.9	2.00	62323.5	.0923	43.08	4.93
5	3.1	3.27	50842.9	.1506	59.52	6.81
6	3.8	4.00	31161.8	.1846	61.77	7.07
7	4.9	5.16	20091.1	.2381	67.46	7.72
8	8.7	9.17	17836.0	.4227	101.42	11.60
9	17.2	18.12	17631.0	.8355	169.75	19.42
10	14.1	14.86	7226.7	.6849	117.83	13.48
11	9.8	10.33	2511.4	.4762	69.35	7.93
12	5.4	5.69	691.9	.2623	32.35	3.70
13	8.1	8.54	518.9	.3935	41.10	4.70
14	16.4	17.28	525.3	.7964	70.43	8.06
15	0.0	0.00	0.0	0.0000	0.00	0.00
16	0.0	0.00	0.0	0.0000	0.00	0.00

*Such data were used to construct the graph shown in figure 2. A total of more than 200 such samples were obtained from the experiment. All data have now been processed to the point demonstrated here.

Table 1

Example of Electronic Particle Count Data (Continued)

Sample:
May 8, 1981 0.2 m 1000 h Replicate 2
Volume counted (ml): .5
Total counted: 156291
Total counted (per ml): 312582.000002
Total volume (cubic millimeters/liter): 4.6238275442
Total carbon (micrograms/liter): 885.254069821

Channel	Percent Volumes	Correct Percent Volumes	Numbers (Per ml)	Volumes (Cubic mm (Per Liter)	Carbon (UG per Liter)	Percent Carbon
1	0.0	0.00	0.0	0.0000	0.00	0.00
2	0.0	0.00	0.0	0.0000	0.00	0.00
3	1.5	1.54	96463.1	.0714	39.37	4.45
4	2.0	2.06	64308.8	.0952	44.45	5.02
5	3.2	3.30	51447.0	.1524	60.22	6.80
6	4.0	4.12	32154.4	.1905	63.74	7.20
7	4.9	5.05	19694.6	.2334	66.13	7.47
8	9.3	9.58	18689.7	.4429	106.27	12.00
9	17.9	18.43	17986.4	.8524	173.17	19.56
10	15.0	15.45	7536.2	.7143	122.87	13.88
11	10.7	11.02	2687.9	.5096	74.23	8.39
12	4.8	4.94	602.9	.2286	28.19	3.18
13	8.4	8.65	527.5	.4000	41.78	4.72
14	15.4	15.86	483.6	.7331	64.83	7.32
15	0.0	0.00	0.0	0.0000	0.00	0.00
16	0.0	0.00	0.0	0.0000	0.00	0.00

Table 1

Example of Electronic Particle Count Data (Continued)

Sample:
May 8, 1981 0.2 m 1000 h Replicate 3
Volume counted (ml): .5
Total counted: 156761
Total counted (per ml): 313521.999999
Total volume (cubic millimeters/liter: 4.36025649054
Total carbon (micrograms/liter): 854.322370228

Channel	Percent Volumes	Corrrect Percent Volumes	Numbers (Per ml)	Volumes (Cubic mm Per Liter)	Carbon (UG Per Liter)	Percent Carbon
1	0.0	0.00	0.0	0.0000	0.00	0.00
2	0.0	0.00	0.0	0.0000	0.00	0.00
3	1.7	1.70	100202.7	.0742	40.90	4.79
4	2.1	2.10	61889.9	.0917	42.78	5.01
5	3.5	3.50	51574.9	.1528	60.37	7.07
6	4.4	4.40	32418.5	.1920	64.27	7.52
7	5.4	5.41	19893.2	.2357	66.79	7.82
8	10.3	10.31	18972.2	.4496	107.88	12.63
9	19.2	19.22	17682.8	.8380	170.24	19.93
10	15.1	15.12	6953.4	.6590	113.37	13.27
11	10.8	10.81	2486.6	.4715	68.67	8.04
12	4.7	4.70	541.1	.2051	25.30	2.96
13	8.8	8.81	506.5	.3841	40.11	4.70
14	13.9	13.91	400.1	.6065	53.63	6.28
15	0.0	0.00	0.0	0.0000	0.00	0.00
16	0.0	0.00	0.0	0.0000	0.00	0.00

Table 1

Example of Electronic Particle Data (Continued)

Average of the previous three replicates
Total counted (per ml): 311956.666666
Total volume (cubic millimeters/liter): 4.53137098886
Total carbon (micrograms/liter): 871.264130661

Channel	Numbers (Per ml)	Volumes (Cubic mm Per Liter)	Carbon (UG Per Liter)
1	0.0	0.0000	0.00
2	0.0	0.0000	0.00
3	98357.1	.0728	40.15
4	62840.7	.0931	43.44
5	51288.3	.1519	60.04
6	31911.6	.1890	63.26
7	19893.0	.2357	66.79
8	18499.3	.4384	105.19
9	17766.7	.8420	171.05
10	7238.7	.6861	118.02
11	2562.0	.4858	70.75
12	612.0	.2320	28.61
13	517.7	.3925	41.00
14	469.7	.7120	62.97
15	0.00	0.0000	0.00
16	0.00	0.0000	0.00

NA5081 is file name for numbers/ml.
VA5081 is file name for volume (cubic mm/l)
CA5081 is file name for carbon (ug/l)

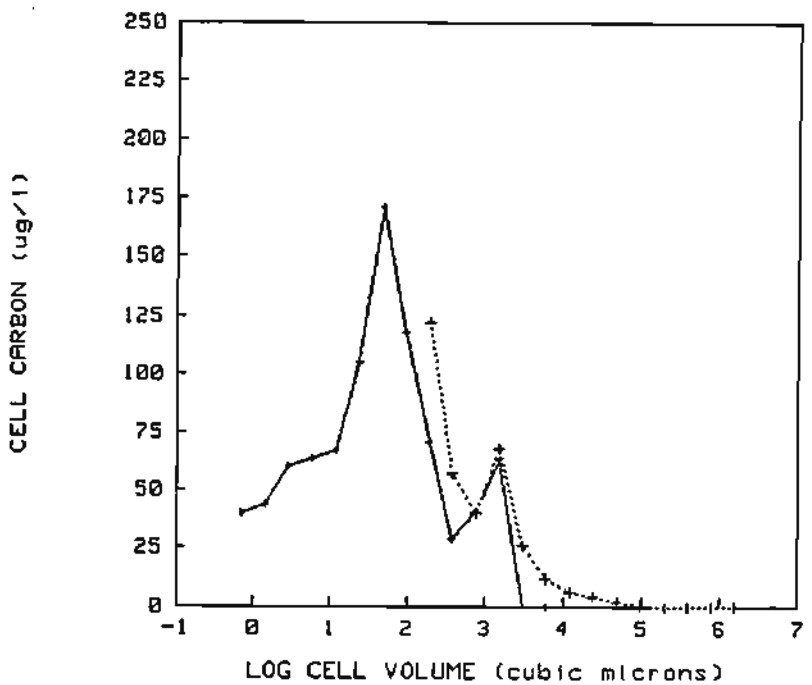


Figure 1. Example of electronic cell count data from SIO deep-tank experiment (see table 1). May 8, 1981; 0.2 m; 1000 h.

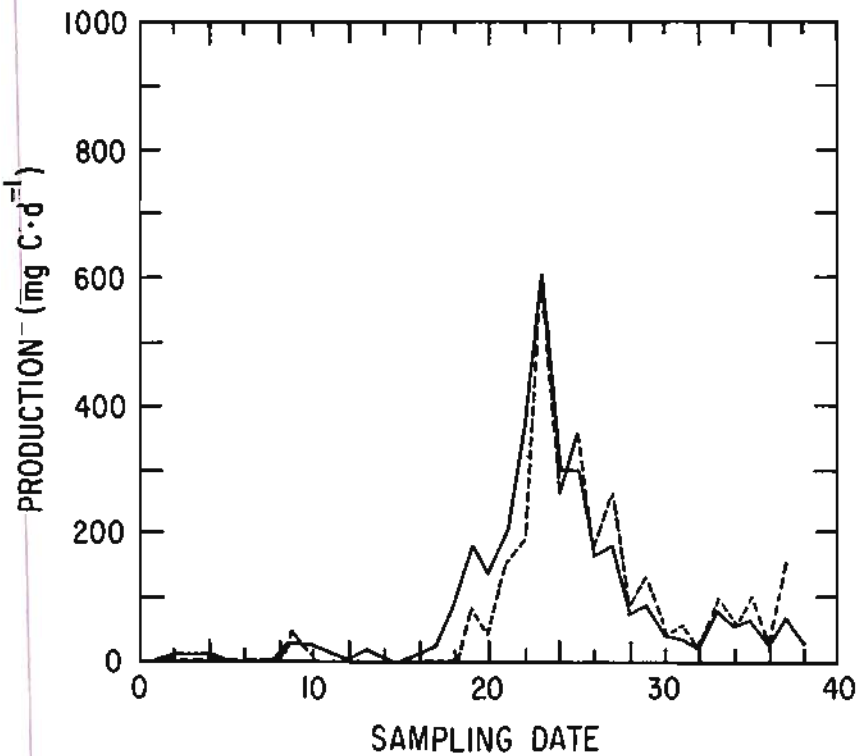


Figure 2. Total production versus time using the cohort analysis approach (solid line) and the weight-dependent approach (dotted line).

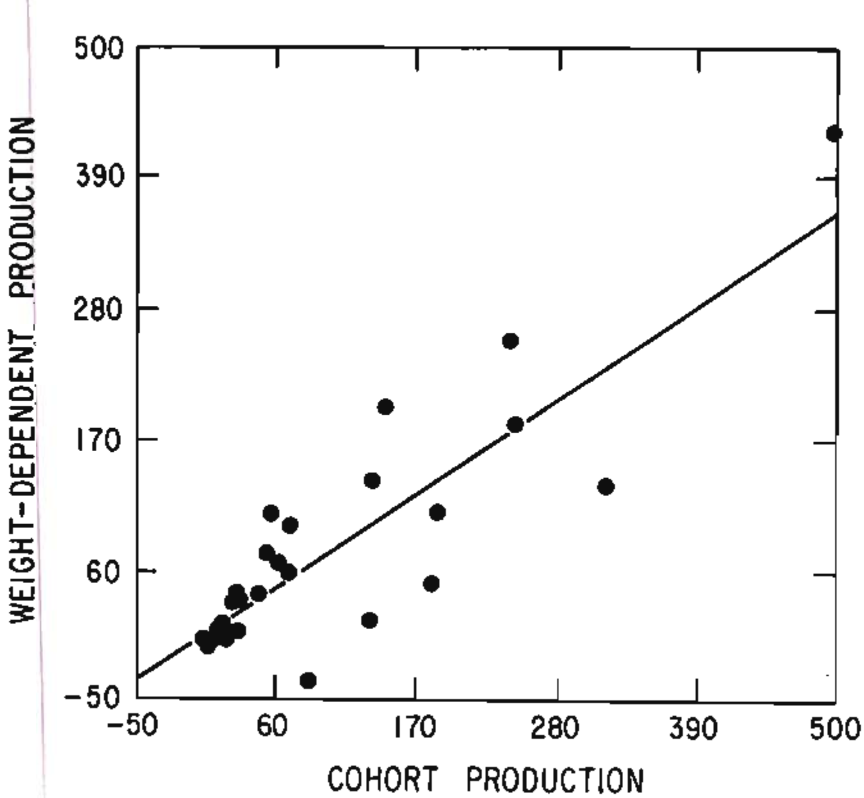


Figure 3. Bartlett's least square regression showing agreement between results of cohort analysis and weight-dependent approaches.

Publications

GOODMAN, D. AND HUNTLEY, M. In prep. Calculation of mortality rates for populations of marine zooplankton.

HOLM-HANSEN, O. AND HUNTLEY, M. In press. 1983. Feeding requirements of krill in relation to food sources. J. Crust. Biol.

HUNTLEY, M. April 1981. A new method for estimating the energy available to fisheries. Invited speaker, Southern California Coastal Water Resources Project, Long Beach, California.

HUNTLEY, M. AND BROOKS, E. R. In press. 1982. Effects of age and food availability on diel vertical migration of *Calanus pacificus*. Mar. Biol.

HUNTLEY, M. In prep. Food-limited growth of marine zooplankton.

HUNTLEY, M. In prep. A method for estimating the production of marine zooplankton: calibration with cohort analysis.

HUNTLEY, M. E., BARTHEL, K.-G., AND STAR, J. L. Submitted. Particle rejection by *Calanus pacificus*: discrimination between similarly sized particles. Mar. Ecol. Prog. Ser.

FUNCTIONAL STRUCTURE OF FISH ASSEMBLAGES OF THE SOUTHERN CALIFORNIA SUBLITTORAL SOFT-BOTTOM HABITAT

University of California, San Diego
R/F-63
1980-81

Richard Rosenblatt and M. James Allen

The predominant bottom habitat for fishes along the mainland shelf of southern California consists of sandy and muddy sediments. The fishes living in this zone are subjected to a commercial trawl fishery in the Santa Barbara Channel and to deepwater (60-100 m) municipal sewage discharge at several points along the southern California coast.

As a consequence of the lack of knowledge of the organization of the fish assemblages, management of this fishery resource has, of necessity, focused upon individual species rather than upon the fish community as a unit. This has hampered our ability to understand changes in populations and to determine underlying causes. A description of the trophic and resource partitioning relationships of the fish species within these assemblages allows alterations in the structure and composition of these assemblages to be identified and examined more thoroughly. This study describes the resource partitioning relationships of the soft-bottom fish assemblages of the southern California shelf.

This study consists of six parts:

1) Samples of the fish fauna were collected by otter trawl along the southern California shelf to a depth of 200 m to obtain size and distributional data on the fishes.

2) The fish assemblages were described in terms of their species composition.

3) The feeding habits of the species that live together in the assemblages were determined by examining their stomach contents and their capture and sensory morphology.

4) Species that feed in a similar way were classified in feeding guilds.

5) The depth and size relationships of the species in each guild were described.

6) The depth displacement graphs of each species were arranged in a way that describes what feeding guilds and what species of each feeding guild is found at that depth.

Data on the depth, geographic, and size distribution of fishes of southern California have been collected by a number of agencies and institutions using small (i.e., 24-foot headrope) otter trawls since 1912. From 1972 to 1973, 343 otter trawl samples from 100 stations were collected to determine size and depth distributions of the species and recurrent groups. The stations were located near the center of the mainland shelf of southern California and off Santa Catalina Island to depths of 200 m. The catches were dominated by pleuronectiform (i.e., flatfish) and scorpaeniform fishes (i.e., rockfishes, sculpins, poachers, and combfishes). The most frequently occurring species were the Dover sole (*Microstomus pacificus*), stripetail rockfish (*Sebastes saxicola*), and Pacific sanddab (*Citharichthys sordidus*).

Fish assemblages were defined using recurrent group analysis (Fager, 1957, 1963), a simple form of cluster analysis. Recurrent group analysis shows which species of the 123 taken are most characteristic of the habitat. At the 0.50 level of affinity, 30 species (about 24% of the total species taken) were important community members. Seven recurrent groups with two to seven species per group and seven closely associated nongroup species were identified (Allen, 1977). These groups were generally distributed over three major depth zones: 10-70 m, 30-130 m, and 90-400 m. Most groups contain pleuronectiform and scorpaeniform fishes, but in shallow water separate groups of schooling perciform fishes (i.e., surfperches and croakers) occurred. Recurrent groups identified in this analysis agree in general with those in other similar data sets (SCCWRP, 1973; Mearns, 1974).

Species that occur together in the recurrent groups were generally morphologically different (particularly with respect to structures that related to foraging behavior), and those that were most similar were found in different recurrent groups (usually at different depths). These morphological differences suggest feeding differences.

The foraging behavior of the most commonly occurring fish species was inferred from their diet and morphology. To determine the diet, 1013 stomachs of the 40 most common fish species were examined. Of these, 561 (about 55.4%) contained food. These stomachs contained 17,556 prey individuals. Four hundred and sixty-one species of prey from 218 families and 31 classes were identified in these stomachs. Gammaridean arthropods were the most important groups of crustacea occurring in 35 stomachs, with calanoid copepods and crabs (Reptantia) each occurring in 27 fish species. An average of 5.0 prey species were found in each stomach, ranging from a high average of 22.2 in the black perch (*Embiotoca jacksoni*) to a low average of 1.1 in the California lizardfish (*Synodus lucioceps*). The calico rockfish (*Sebastes dalli*) ate the greatest numbers of prey (averaging 316.9 prey items per stomach) and the California lizardfish ate the least (1.2 on the average). The sablefish (*Anoplopoma fimbria*) ate the largest prey (8,817.2 mm^3 on the average), and the shiner perch (*Cymatogaster aggregata*) ate the smallest (averaging 0.6 mm^3).

In general, recurrent group species showed feeding differences that correspond to those predicted from their morphology. The major separation, as shown by the species that occur together most frequently, is related to the orientation of the species with respect to the bottom. Using bottom orientation as the major separation, species were classified into guilds with minor differences in foraging behavior generally being related to the use of different sense organs.

A typical fish community at any depth contains at least thre species of flatfish, a large-mouth species with symmetrical jaws (e.g., a sanddab) that feeds on actively moving prey at or above the bottom, and two species with small, asymmetrical mouths (e.g., turbots and soles) that feed on the bottom. Usually one of these species finds its food visually and the other uses other sense organs (such as those associated with touch or smell) in addition to or instead of sight. Also on the bottom one typically finds at least two roundfish species that lack swimbladders, usually a short-bodied sedentary form (e.g., a sculpin or poacher) and an elongate form (e.g., a combfish) that forages more widely and actively. Above the bottom there are usually at least two species that forage in the water and two that forage on the bottom. Those that forage in the water generally include a species that locates its food visually (e.g., a rockfish, surfperch, or croaker) and one that uses lateral line organs in addition to sight (e.g., a midshipman). Bottom foragers also include a diurnally active visual forager (e.g., surfperch) and nocturnally active foragers that utilize other sense organs (e.g., croakers).

Species within a guild are generally separated from each other by depth or size. Depth displacement graphs for each guild generally show an overlap zone where two displacing species coexist and include from two to four displacing species of the depth range from shore to 200 m.

A set of the depth displacement graphs for each guild was arranged to describe the functional structure and species composition of the soft-bottom fish assemblages of the southern California shelf. The structure is described in terms of the number and type of feeding guilds represented at each depth and the composition is described in terms of what species of each guild dominates at each depth. Otter trawl samples can then be collected at a particular depth and compared to this chart to determine what species are missing or added.

The alterations that one might expect to find include the following:

1) All guilds are represented at a given depth but the dominant species in a particular guild differs from that predicted for that depth. In this case, the community structure has not been altered but the species composition has been altered. Further studies would investigate factors occurring at that depth that might shift the advantage from one species to another within the same guild and thus result in a change of dominance.

2) A guild is not represented at a particular depth. This might occur because the food organisms upon which the guild members typically feed are absent, in which case factors that contribute to the absence of the food organisms should be studied. Alternatively, food organisms may be available and the guild may not be represented because of other reasons (i.e., pollution, predation, fishing, recruitment, etc.). In this way, alterations in community structure and composition can be identified and studied further along with factors that contribute to the overall organization.

Cooperating Organizations
County Sanitation Districts of Los Angeles County
County Sanitation Districts of Orange County
Lockheed Center for Marine Research
Marine Review Committee
Orange County Department of Education
Pacific Bio-marine
Scripps Institution of Oceanography
Southern California Coastal Water Research Project

References

ALLEN, M. J. 1977. Pollution-related alterations of southern California demersal fish communities. Cal-Neva Wildlife Transactions 103-107.

FAGER, E. W. 1957. Determination and analysis of recurrent groups. Ecology 38:586-593.

FAGER, E. W. 1963. Communities of organisms. In *The Sea, Vol. II*, M. N. Mill, ed. Wiley-Interscience, New York. pp. 415-433.

MEARNS, A. J. 1974. Southern California's inshore demersal fishes: Diversity, distribution, and disease as responses to environmental quality. Invest. Rep. #18. Calif. Coop. Ocean Fish. pp. 141-148.

SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT, 1973. The ecology of the southern California bight: implications for water quality management. Tech. Rep. 104. Southern California Coastal Water Research Project.

Publications

ALLEN, M. J. 1981. Functional structure of southern California level-bottom fish communities. Presented at American Society of Ichthyologists and Herpetologists, Oregon State University, June 1981.

ALLEN, M. J. 1981. Functional structure of level-bottom fish communities of the southern California shelf. Presented at California Cooperative Oceanic Fisheries Investigations, Idyllwild, California, October 1981.

ALLEN, M. J. 1981. Large scale considerations in studies of resource partitioning. Presented at Pacific Technical Workshop, Fish Food Habits Studies, Monterey, California, December 1981.

ALLEN, M. J. 1981. Resource division among soft-bottom fish species of the southern California shelf. Presented at Southern California Academy of Sciences, California State University, Los Angeles, May 1981.

ALLEN, M. J. In prep. 1981. Functional structure of southern California soft-bottom fish assemblages. Ph.D. dissertation.

ANCHOVY MANAGEMENT AND STOCK ASSESSMENT: SEABIRD REPRODUCTION AS AN INDICATOR

University of California, Irvine
R/F-64
1980-82

George L. Hunt

The purpose of our Sea Grant research project was to test the idea that seabirds, in particular the western gull (*Larus occidentalis*) and the Xantus' murrelet (*Endomychura hypoleuca*) could be used as biological indicators of northern anchovy (*Eugraulis mordax*) availability in the Southern California Bight. Additionally, using the same study, we wished to determine anchovy population levels necessary to sustain populations of top carnivores, such as seabirds, dependent on these forage fishes. The 1982 season concludes this study, as funding was terminated.

Our approach to the problem has been to compile, with the help of the National Marine Fisheries Service, data on anchovy abundance to compare with data on seabird numbers and reproduction.

In our investigations of anchovy availability, we have concentrated, as a first effort, on the use of aerial spotter pilot logs of anchovy sightings in the area where western gulls and Xantus' murrelets nesting on Santa Barbara Island forage. Eventually, we will also compare other indices of anchovy abundance (egg and larval counts, spawning female, acoustic survey) with our bird data. At present we have data from pilot logs available through 1980, which gives us 7 years of data to compare birds and fish populations.

As measures of bird reproductive activity, we have been recording 1) the number of pairs of western gulls breeding on Santa Barbara Island, 2) the hatch and fledging success of nests in large, consistently studied grids, 3) the growth rates of young, and 4) the foods brought to young.

Results of this work, prior to Sea Grant funding, were published in 1980 in CalCOFI Reports (Hunt and Butler, CalCOFI Rep. 21:62, 1980). Since then, we have added 5 years of data on gull numbers, reproductive success, and growth rates. Food samples were gathered in 1981 and 1982 with Sea Grant support, and 1982 data are being worked up at present. The results of these new, Sea Grant-supported efforts are presented in table 1.

Numbers of breeding gulls over the full term of the study show a significant correlation with our index of anchovy abundance for the first quarter of each year ($r = 0.853$, $p < .01$). Most recently, numbers of breeding gulls were correlated with the anchovy abundance index in 1978 and 1980, but in 1979 gull numbers went up while anchovy sightings in the first quarter were zero. The zero figure may have been due to lack of effort resulting from a closure, as larger numbers of anchovies were seen in the second quarter of 1979. We were planning to develop a new, more sensitive index of anchovy abundance based on tons per entry in which tonnage was reported for the months of March, April, and May, when food should be most critical to gulls, but with the cessation of funding, this may not be possible. The use of anchovies to feed chicks was also significantly correlated to the index of anchovy abundance for the first quarter of each year ($r = 0.89$, $p < .005$).

Data on growth rates in relation to chick foods are awaiting completion of the identification and tabulation of foods brought to chicks in 1982. We still find a significant relationship between chick growth and survival ($r = 0.63$, $p < .05$), although this correlation is less strong than we first reported. Chick survival and anchovy use also remains significantly correlated ($r = 0.61$, $p < .05$), although there is not a significant relationship between growth rates and anchovy use ($r = 0.38$, $p < .05$). Thus, our results from 1979-82 have generally agreed with the results published by Hunt and Butler (1980) and confirm that there are significant relationships between anchovy sightings and seabird reproduction.

James Sayce, the Sea Grant trainee on this project, has gathered a variety of very interesting observations while obtaining the seabird data for the Sea Grant project. While following up on growth rates of known-sex chicks, he discovered that male chicks may be more sensitive to food availability than female chicks and that males are more likely to fledge underweight than females. If this is true, it could provide a mechanism for understanding the skewing of sex ratios in gulls, and in particular in the western gull.

Sayce has also found variation in foods used from one part of the colony to another and obtained some limited data on the dynamics of gull foraging at sea. In this project, he has determined gull densities during boat transects and then chummed gulls to the boat with bait. The number of gulls attracted divided by the density of the birds in the area gives a measure of the area from which gulls are attracted.

Table 1

Summary of Data on Anchovies and Western Gulls, Santa Barbara Island

	Anchovy Index[a] 1st Quarter	Anchovy Index 2nd Quarter	Pairs of Western Gulls Breeding	Growth Rates[b] of Gull Chicks	% Survival[c] Gull Chicks	Anchovy Use % Volume
1972	1448	64	1510	28.5	.85	45.0
1973	157	177	-	-	-	-
1974	218	142	-	-	-	-
1975	443	1642	1162	29.0	.91	32.0
1976	309	428	1120	22.5	.66	28.2
1977	80	195	896	29.9	.96	17.8
1978	51	126	425	26.0	.28	17.7
1979	0	550	700	23.0	.48	5.2
1980	d	d	500	27.4	.46	9.3
1981	d	d	750	22.2	.33	15.0
1982	d	d	750	25.4	.83	d

[a] Anchovy index = tons sighted/entries into area of sighting
[b] Growth rate = grams/day between weights of 150 and 600g
[c] % Survival = chicks hatched surviving to 500g
[d] Data not yet available for tabulations

PARASITES AS BIOLOGICAL TAGS FOR PACIFIC HERRING STOCK IDENTIFICATION

University of California, Santa Cruz
R/F-65
1980-81

Mike Moser

The goal of this project is to determine the possible use of parasites as biological indicators of herring stock separation and recruitment. Although this study was only funded for the 1980-81 fiscal year, further collections will be necessary during the 1981-82 spawning season. Also, the select organs have yet to be examined for the presence of parasitic protozoa.

Results

One hundred fish, 50 of each sex, were collected from each of the following sites: Monterey, San Francisco, Tomales, and Humboldt bays and off Crescent City. Fish were fresh frozen and examined at UC Santa Cruz. The prevalence and the intensity of the crustacean and helminth parasites are given in table 1. The presence of a possible saprolegnia-like fungus was reported from the muscle tissue of all fish examined.

Sex Differences. There were several cases where one sex of fish had a significantly higher prevalence (P) and/or intensity (I) of parasites (Mann-Whitney). *Bucephalidae* larvae: San Francisco Bay, P = males 76, females 46; Tomales Bay, P = males 96, females 72; Crescent City, P = males 67, females 59 and I = females 5.2, males 3.5. *Lacistorhynchus tenuis*: Crescent City, P = males 39, females 16.

Area Differences. San Francisco Bay (SFB) and Tomales Bay (TB) were shown to differ significantly in the P and I for several parasite species. San Francisco Bay had significantly higher P and I for *Lacisthorhynchus tenuis* and *Anisakis* and a higher I for *Contracaecum/ Hysterothylacium.* Tomales Bay had a higher P for *Bucephalidae* larvae. When Crescent City (CC) was compared to Humboldt Bay (HB), HB had a greater P for hosts infected with *Bucephalidae* larvae and a higher I among the male hosts. Crescent City had a higher P for *L. tenuis.*

Large Tomales Bay Fish. *Anisakis* and *Lacistorhynchus* larvae found in 30 fish exceeding 185 mm from TB were compared to smaller fish from this bay. In addition, larger TB fish were also compared to the hosts from SFB, HB, and CC. For the larger TB fish, the P and I for *Anisakis* were 100 and 45.2 respectively. *Lacistorhynchus* was P = 63 and I = 3.5. For *Anisakis*, the larger TB fish had a greater P and I than SFB fish. The larger TB fish also had a greater P than the smaller TB hosts. The *Lacistorhynchus* larvae were found in greater P and I in large TB fish than in hosts from both CC and HB. The I of these larvae from larger TB fish was greater than in the small fish from this area. However, SFB hosts had a greater P and I of *Lacistorhynchus* than both the larger and smaller TB fish.

Discussion

These data are not complete, hence this discussion is preliminary. Nevertheless, several interesting aspects of this study are emerging. For example, only the 1- and 2-year-old fish from MB were infected with digenetic trematodes. Older fish from MB and fish from all other areas, regardless of age, lacked these parasites. These infections are probably the result of the availability of the intermediate hosts and the longevity of the digenetic trematode.

Presently there is no ready explanation for the differences in P and I of infections between males and females.

In the use of parasites as biological tags, only fish of the same age can be compared. As a result, fish from SFB could not be compared to those from CC and HB. The size differences in the catch were the result of differences in the fishing techniques used in the different areas. This problem will be corrected in next year's collections. There were considerable differences in the P and I of parasitism between SFB and TB. The fact that the hosts most probably were not infected with these parasites in their respective bays during the 1980-81 spawning season may suggest the possibility of earlier stock separation. This will be further studied as more samples are collected. The differences in P and I of parasitism between CC and HB is less than the differences detected between the southern bays. Monterey Bay lacks a commercial fishery for herring. As a result, it was difficult to obtain herring of the proper age classes for this study. These collections will continue through the 1981-82 spawning season. For the final report, these data, in addition to future work, will include comparisons by ANOVA techniques.

The age of a fish often influences the P and I of parasitic infections. This was shown to be the case in fish greater than 185 mm from TB. This size is comparable to the specimens from HB and CC but larger than those from SFB. The larger TB hosts had comparable *Anisakis* infections to CC and HB, but a greater P and I than SFB fish. Larger and smaller TB fish differed in the P of infections. Hence, for *Anisakis* the differences in P and I is most easily explained by the age of the host and not geographic differences. This is understandable because *Anisakis* has a long life span and can accumulate in a host over a period of time. The differences in P and I of *Lacistorhynchus* larvae, however, can not strictly be attributed to age differences in the hosts. The CC and HB fish were less infected than the larger TB fish. Further, SFB fish had a greater P and I than both the larger and smaller TB hosts. Since larvae are relatively long lived, it appears that these infections may be restricted to certain geographic areas.

Electrophoresis. The following loci were examined: PGI, PGM, ADA, PEP-2, LDH-1, LDH-2. There was no significant difference between the 100 fish each tested from SFB and TB and those same loci reported for herring off Washington.

Table 1

Prevalence and Intensity of Crustacean and Helminth Parasites

	*MB **P/I	SFB P/I	TB P/I	HB P/I	CC P/I
Nematode larvae					
Anisakis sp.	16/1.7	60/4.1	92/8.8	100/50.5	100/44.5
Contracaecum sp.	100/10.4	96/10.6	100/6.2	93/4.4	93/5.8
Hysterothylacium sp.	100/10.4	96/10.6	100/6.2	93/4.4	93/5.8
Fungus (?)	100/-	100/-	100/-	100/-	100/-
Cestode larva					
Lacistorhynchus tenuis	72/3.7	97/10.1	62/1.9	6/1.6	27/1.6
Digenetic trematodes					
Parahemiurus merus	87/7	0/0	0/0	0/0	0/0
Bucephalidae (larvae)	49/3.9	61/2.5	84/3.8	90/7.4	62/4.4
Copepod					
Bomolochus sp.	58/2.3	16/1.0	9/1.0	9/1.1	9/1.0
Caligus sp.	0/0	5/1.4	0/0	0/0	2/1.0
Acanthocephala					
Rhadinorhychus trachuri	0/0	0/0	0/0	5/1.2	0/0

* MB = Monterey; SFB = San Francisco Bay; TB = Tomales Bay; HB = Humboldt Bay; CC = Crescent City

** P/I = Prevalence (percent infected)/Intensity (number parasites per infected fish). No intensity for fungus (?) given.

Cooperating Organizations

California Department of Fish and Game
Fishermen in Monterey, Tomales, and San Francisco bays
University of California, Santa Cruz, Department of Marine Studies
Washington Department of Fisheries

Publications

MOSER, M. In prep. Parasites as biological indicators of herring stock separation and recruitment. In *Manuscript report series of the Canadian Department of Fish and Oceans*. Fourth Pacific Coast Herring Biologist Workshop, Seattle, Washington, October 7-8, 1980.

IMPROVING EFFICIENCY OF COMMERCIAL SHELLFISHING BY ANALYSIS OF BAIT AND TRAP FUNCTIONS

University of California, Santa Barbara
R/F-67
1980-82

James F. Case

In order to define precisely the mechanisms of orientation of commercially valuable crustaceans to traps, we have conducted field and laboratory experiments utilizing a large behavior tank as well as conventional electrophysiological and behavioral studies on restrained animals. Our field experiments are now largely concluded.

Integrated field and laboratory data from our investigations on prey localization by the California spiny lobster (*Panulirus interruptus*) are being used to develop a model of foraging behavior. Development of the model requires 1) precise determination of composition, physical condition, and amount of effective baits; 2) analysis of the initial effects of chemoreception on behavior; 3) determination of the influence of environmental factors such as light and water turbulence on foraging; and 4) the role of social factors and other phenomena collectively characterized as central excitatory state on the initiation and persistence of foraging. The major emphasis during 1980-81 was on testing aspects of foraging strategy revealed in our previous studies in a large observation tank (32 x 8 x 2 ft; 26 ft working section) equipped for precise stimulus control and for low-light level observation.

Field Experiments

Two types of field tests were conducted: to complete the previous year's large bait specificity field study, and to determine stimulant concentrations in the vicinity of normally baited traps.

In the first test, a series of 118 paired casts were made at the previously used More Mesa trapping site to examine the efficacy of intact live and injured prey. Intact mussels, urchins, abalones, and various polychaetes were ineffective attractants for either *Panulirus* or *Cancer*; injured mussels, urchins, and abalones were effective but not as effective as standard chopped bait. We conclude that foraging does not involve tracking of prey species by means of "normal" odorants. Abalone and mackerel tissues were attractive to lobsters but not to crabs, while shark was almost uniquely attractive to crabs. Therefore, it appears unlikely that such odorants are responsible for the marked specificity of certain of these prey organisms for lobsters or crabs when used in chopped formulations. We thus feel justified in proceeding with conventional fractionation studies. These tests were done using ground abalones packed in cut-off tubing with surface exposure of the two types of tubing adjusted to correct for their differing dialysis rates for smaller molecules.

Abalone muscle increased in attractivity following 1-2 days field exposure. Molecular weights of stimulants released by both weathered and fresh abalone were ⩽ 10,000 with evidence suggesting that the 1000- to 10,000-dalton fraction may contribute significantly to attraction. Concentrations of total primary amines released from abalone muscle failed to differ from background levels, following an initial 3-hour (0- to 3-h) period. Primary amines thus appear not to contribute directly to captures of lobsters, since animals were usually caught more than 7 hours after baits were positioned. Amino acids were the dominant contributors to present measurements of total primary amines, suggesting that these molecules may not direct lobster foraging behavior in the present experiments.

In the second study, two types of experiments have been done to refine the precision of our estimates of stimulus concentrations around traps under field conditions. To augment our previous measurements, further studies of weight loss of standard abalone baits were conducted in closed traps under field conditions. (All weight loss was assumed to represent attractant loss.) Another approach to this question has been provided by determining the levels of primary amines released from a natural bait under field conditions. This technique is described in a paper submitted to *Analytica Chimica Acta*. A standard bait container was loaded with 180 gm of ground abalone tissue and placed in a trap at More Mesa provided with nine variously placed sampling parts leading to the surface. Samples were taken at intervals for 47 hours and assayed for primary amines by fluorescence after reaction with O-phthalaldehyde; those data were then converted to glycine equivalent.

Investigations of rates of bait dissolution, direct measurements of primary amines leaching from baited traps under field conditions, and calculations based on the equations for turbulent flow show decisively that effluent concentrations fell to not more than 3×10^{-7} g/liter within 0.5 m of the trap. This value is so close to the absolute behaviorally measured chemoreception threshold (Zimmer-Faust and Case, submitted) that chemically induced direct long-range orientation to traps is impossible. We, therefore, propose that chemical induction of locomotion does not occur but rather that chemical stimulation modulates existing locomotor activity. Lobsters are spontaneously active in darkness and it is likely that chemical excitation during such activity modulates an endogenous motor pattern. Under large tank conditions masking the eyes of lobsters does not materially lengthen search for food, making it likely that search activity relies on tactile and contact chemosensory input superimposed on the endogenous pattern. Experiments in progress seek to determine if this pattern is characterized by more frequent turns during random chemical excitation, this being the most likely search program that would bring the lobster to the bait source under turbulent conditions.

Laboratory Studies

We now have a very effective system of eight small tanks in which the initial stages of chemosensory activiation can be studied during application of precisely known stimulant concentrations. A hierarchical system of acts culminating in chemosensorily induced locomotion has been defined and is used in determining the effectiveness of stimulants of interest in the program. Perhaps the most interesting of those currently under study is the crustacean molting hormone, β-ecdysone. While α-ecdysone is inactive, the arousal threshold to β-ecdysone, as measured by significant increases in antennal flick rates, is at about 10^{-14} M. Walking is triggered at 10^{-8} M. No sexual difference is seen.

This remarkable observation has led to investigations of the electrophysiology and behavior of the antennules. Using conventional recording techniques, antennular receptors have been located that respond significantly to 10^{-11} M β-ecdysone, and their specificity and other properties are now under study. Currently, a new preparation is in use in which flick rates are measured with doppler techniques on antennules chronically externally perfused in a closed system. This has the advantage of insuring that responses noted are initiated in the antennules rather than possibly systemically, as might occur in the usual behavioral tests. Much of the work in developing this most useful preparation was done by Dr. Y. C. Siew, a visitor from the University of Malaysia. It promises to be most useful in differentiating between systemic and receptor effects of toxicants.

While we have characterized dactyl and antennular chemoreceptors sufficiently for purposes of modeling behavior by means of our 1964 recording methods, new approaches are clearly desirable. Intracellular recordings from more than 50 antennular chemoreceptor cells show resting potentials averaging 58 mV. Only one cell in this series spiked, suggesting either that these very small cells are damaged or that the spike initiates in the proximal axon. Recordings with glass suction electrodes from the axon bundle just central to the cell body clump at the base of a receptor hair reveal spikes from dozens of cells. Currently this technique is being perfected to allow determination of the chemoreceptive spectrum of single receptor hairs.

A chronic indwelling electrode technique has been developed that allows recording of massed chemoreceptor activity from antennules of restrained lobsters for several days. Currently this technique is being used to assess long-term adaptation to stimulants. It is hoped that the method can be adapted to unrestrained animals in small behavior tanks so that the relationship between chemoreceptor input and behavioral arousal to chemical excitants may be determined.

Large Behavior Tank Studies

Much of the year has been devoted to constructing a large behavior tank, enclosing it to provide an adequate light regimen, and equipping it for investigations of chemoreceptive orientation as affected by social and other factors. The 26-foot working section is fitted with windows in the sides and bottom to allow video recording of behavior with a low-light system able to provide clear viewing of the details of behavior at even lower light levels than those that normally occur during foraging. The tank is provided with lobster "habitats" which interfere minimally with water flow and which may be placed over a bottom window to allow detailed observation of chemoreceptive behavior.

While flow and stimulant metering calibrations are still in progress, preliminary experiments have shown that the tank will be most valuable for the final phase of the program: investigation of long-range orientation to baits and behavior at trap entries. These preliminary tests show that, even though lobsters will not leave their habitats during daylight, they show all the behavior characteristic of food-induced arousal while remaining in the habitat. Search activity is maximal in the first 2 hours of darkness. During this period, long-range orientation along the edges of stimulus plumes in smoothly flowing water does occur. We are now able to proceed to direct examination of such matters as search strategy upon stimulus interruption, social interactions during food arousal, and the problem of optimizing capture once a trap has been located.

Conclusions

In brief, our studies have 1) scientifically demonstrated for the first time a clear-cut species discrimination among commonly used baits, 2) determined the rate of bait dissolution necessary for efficient trapping, 3) empirically established the odorant concentration field around traps, 4) ascertained the contribution of vision to bait localization, and 5) determined that there exists a social factor in search behavior. In addition, work still in progress is revealing important details of the physiology of the chemoreceptive sensilla mediating search behavior. Most recently the latter studies have resulted in a method for electrophysiologically recording from the sensory afference of a single, defined antennular chemoreceptor organ.

Finally, it may be appropriate to mention that, among the trainees on the project, two have gone on to appropriate related employment. Dr. Katherine Hamilton is now a post-doctoral fellow investigating chemoreception in Florida *Panulirus* at the Whitney Marine Biomedical Laboratory of the University of Florida. Dr. Richard Zimmer-Faust has just received a 2-year fellowship to investigate problems in food-search strategy in prawns and other crustaceans jointly with the University of Queensland and the C.S.I.R.O. Northeastern Regional Fisheries Laboratory, Cape Cleveland, Queensland.

Cooperating Organizations
American Seafood
C.S.I.R.O., Melbourne
Office of Naval Research
SeaFood Specialties
University of Malaysia

Publications

HAMILTON, K. A. Submitted. 1981. Aging effects on chemoreceptor setal morphology. Physiological Zoology.

HAMILTON, K. A. AND CASE, J. F. Submitted. 1981. Effects of abrasion, low external sodium and TTX on dactylopodite mediated chemoreception. Physiological Zoology.

HAMILTON, K. A. H. 1980. Dactyl-mediated chemoreception in the kelp crab, *Pugettia producta* (Randall). Ph.D. thesis.

HAMILTON, K. A. H. In press. 1982. Post-larval changes in external morphology of dactyl setae. J. Exp. Zool.

HAMILTON, K. A. H. AND CASE, J. F. In press. 1982. Effects of abrasion and sodium ions on dactyl mediated chemoreception. J. Exp. Zool.

PETTY, R. L., MICHEL, W. C., AND SNOW, J. Submitted. 1981. Flow injection analysis of seawater and other fluids: total primary amines. Analytica Chimica Acta.

ZIMMER-FAUST, R. K. 1980. Organization of food search behavior in the kelp crab *Pugettia producta*. Am. Zool. 20:885.

ZIMMER-FAUST, R. K. 1982. The influence of odors on food search: Studies with marine decapod crustacea. Ph.D. thesis.

ZIMMER-FAUST, R. K. AND CASE, J. F. 1981. Organization of food search in the kelp crab *Pugettia producta* (Randall). J. Exp. Mar. Biol. Ecol.

ZIMMER-FAUST, R. K. AND CASE, J. F. 1982. Odors influencing foraging behavior of the California spiny lobster *Panulirus interruptus*, and other decapod crustacea. Mar. Behav. Physiol. 9:35-58.

ZIMMER-FAUST, R. K. AND MICHEL, W. M. 1980. Induction of feeding behavior in the spiny lobster, *Panulirus interruptus* by molecular weight fractions of abalone (*Haliotis* spp.). Am. Zool. 20:753.

SEAFOOD SCIENCE AND TECHNOLOGY: MODIFIED ATMOSPHERE STORAGE

University of California, Davis
R/F-68
1980-82

W. D. Brown

Seafood products are particularly susceptible to deteriorative post-mortem changes, including those of a physical and chemical nature as well as those due to microbiological spoilage. The distribution of fresh fish, particularly, is limited because of short shelf life and resulting losses due to spoilage. Adverse changes in quality likely are responsible for the low per capita consumption of fresh fish in this country, in spite of the fact that, when quality is assured, fresh fish is preferred by most consumers.

There is a need for the development of new technologies for handling fresh seafood products. One such technology showing great promise is the use of modified atmospheres (MA), particularly those containing high levels of carbon dioxide. There is a possibility that MA technology ultimately can be employed in the packaging steps of distribution as well as for bulk shipping or storage of fresh seafood products.

The overall goal of this research project is to study the use of such atmospheres in the hope of providing technological advances for improved handling and distribution of a variety of seafood products. It is anticipated that innovative use of this technology will lead to improved product quality, significant extension of the distribution range for fresh seafood, and greater utilization of marine food resources.

Modified Atmosphere (MA) Storage of a Variety of Seafood

We have employed rockfish fillets, dungeness crab, and crayfish in these studies. Most of the research to date dealing with the application of MA systems had involved the use of CO_2 concentrations of 60% or lower. Our own earlier work had suggested that higher levels of CO_2 might be even more effective. Consequently these studies were aimed at evaluating the effectiveness of atmospheres highly enriched with CO_2, i.e., at the 80% level.

The products used in these studies were held in atmospheres containing 80% CO_2 and balance air, and quality was measured by common microbiological and chemical indices, accompanied by sensory panel evaluations; comparisons were drawn between samples held in MA and controls held in air. All samples were held refrigerated at 35 ± 2°F.

Aerobic plate counts and trimethylamine levels were significantly lower ($P < 0.1\%$) for samples held in MA compared to those held in air. The production of trimethlylamine generally is considered to be responsible for the fishy odor of spoiling fish, hence inhibition of its production is highly desirable. Since the production of trimethylamine from the odorless trimethylamine oxide (commonly found in fish) is microbiological in nature, it is logical that bacterial counts and trimethylamine levels should be related. The lower levels of both in the fish held in carbon dioxide is a desired result. Controls and samples of rockfish held in modified atmospheres show similar behavior for 3 days, at which time the levels of trimethylamine begin to increase in the controls. Levels were substantially higher in the air control samples at 7 days, and were particularly striking at the 10- and 14-day sampling periods (figure 1).

A decline in surface pH was observed on all samples stored in MA, presumably due to the absorption of CO_2 and its conversion to carbonic acid. Oxidation-reduction potential measurements suggested that there was a more aerobic environment on fish stored in MA. There were no significant differences in weight loss between control and treatment groups. Sensory evaluations indicated that samples held under MA were of consistently better quality than controls. Figure 2 shows pH data obtained in our crayfish study.

Use of Modified Atmospheres and Chemical Preservatives in Retail Packs

Trials have been initiated to determine the effect on shelf life of rockfish fillets packed in retail size plastic bags as affected by MA and/or chemical preservatives. Samples were vacuum-packed in either an MA containing 80-85% CO_2 or in air (controls), with or without chemical preservatives, including EDTA, potassium sorbate, sodium benzoate, and chlortetracycline (CTC). Treatment with sorbate CTC has been particularly effective so far. Indices of spoilage measured included trimethylamine, ammonia, surface pH, surface oxidation-reduction potential, total plate count, and sensory analyses. The latter involved evaluation of odor, flavor, and color in comparison with fresh samples.

Factors Involved in Myoglobin Oxidation

The use of MA containing high levels of carbon dioxide leads to an enhancement of the oxidation of the muscle pigment, myoglobin. It is therefore of interest to understand this reaction, and means of its reversal, including enzymatic reduction of the oxidized product, metmyoglobin.

We have now isolated the enzyme metmyoglobin reductase from tuna muscle, and it is being characterized and its enzymatic properties determined. We are hopeful that better knowledge of this enzyme may help us utilize the enzyme's action in fish muscle.

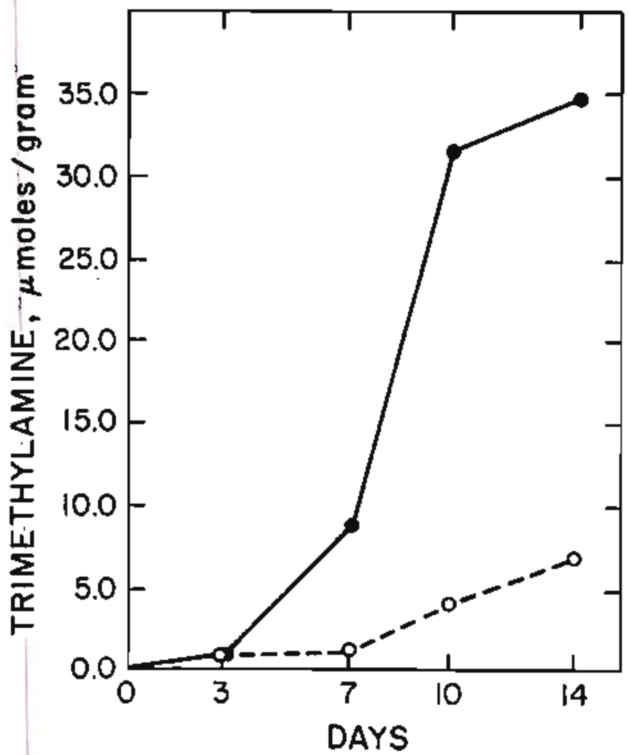


Figure 1. Levels of trimethylamine in rockfish fillets held in modified atmospheres (○) and in air (●) at 35°F.

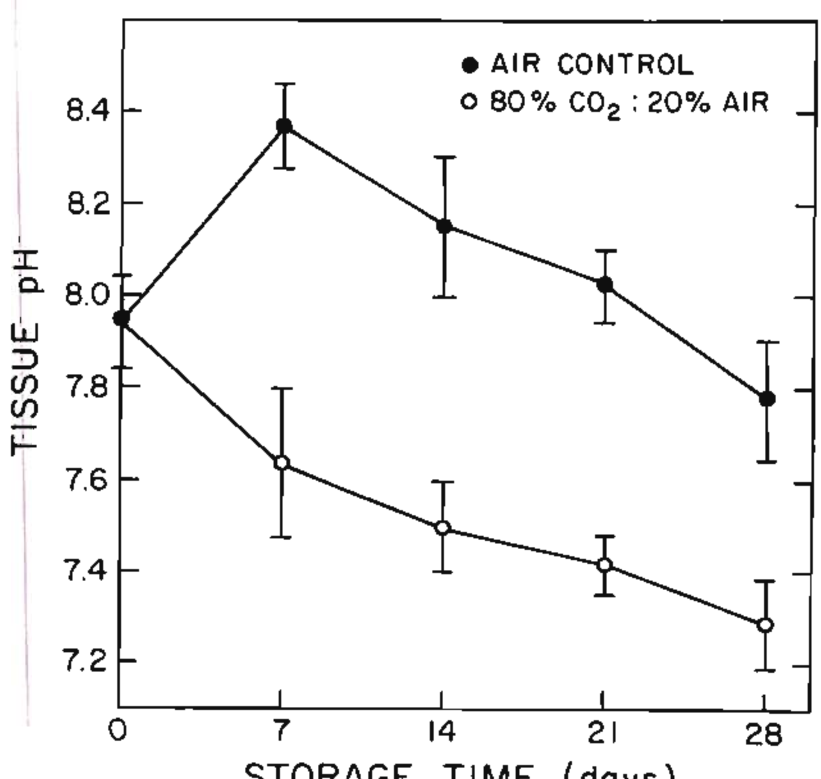


Figure 2. Changes in pH in crayfish held in MA or in air. Bars denote standard deviations.

Cooperating Organizations
Cryovac Corporation
Meredith Fish Co.
Star-Kist Foods

Publications

LIVINGSTON, D., LAMAR, G. N., AND BROWN, W. D. In press. Myoglobin diffusion in bovine heart muscle. Science.

MOREY, K. S., SATTERLEE, L. D., AND BROWN, W. D. 1982. Protein quality of fish in modified atmospheres as predicted by the C-PER assay. J. Food Science 47:1399-1400 and 1409.

PARKIN, K. L. AND BROWN, W. D. 1982. Preservation of seafood with modified atmospheres. In *Chemistry and biochemistry of marine food products*, R. E. Martin, G. J. Flick, C. E. Hebard, and D. R. Ward, eds.

PARKIN, K. L. AND BROWN, W. D. In press. Modified atmosphere storage of dungeness crab. J. Food Science.

PARKIN, K. L., WELLS, M. J., AND BROWN, W. D. 1982. Modified atmoshpere storage of rockfish fillets. J. Food Science 47:181-184.

WATTS, D. A. AND BROWN, W. D. 1982. Histamine formation in abusively stored Pacific mackerel: effect of CO_2 modified atmospheres. J. Food Science 47:1386-1387.

SEAFOOD SCIENCE AND TECHNOLOGY: MICROBIOLOGY OF FISH

University of California, Davis
R/F-69
1980-82

E. L. Barrett and David M. Ogrydziak

The objectives of this project were to enumerate microbial counts of rock cod stored in air and modified atmosphere (MA) using different incubation temperatures and atmospheres, initiate taxonomic identification of predominant microbial groups involved in spoilage of air- and MA-stored rock cod, and search for food-borne disease microorganisms in rock cod stored in air and MA at 4°C.

Fresh rock cod fillets were stored in air or MA (80% CO_2/20% air) atmospheres at 4°C. At intervals of 0, 7, 14, and 21 days, samples were removed and subjected to microbiological analyses. The enumeration plates were incubated aerobically at 4, 20, and 35°C; under MA at 4, 20, and 35°C; and anaerobically at 35°C. The day 0 counts were 5 x 10^4 to 1 x 10^6 for plates incubated aerobically and 1 x 10^3 to 7 x 10^4 for plates incubated anaerobically or under MA. After 7-day storage in air, the fillets were obviously spoiled and had a 3- to 4-cycle increase in microbial counts. For the air control samples, the experiment was run for only 14 days due to the bad organoleptic condition of the fillets by this time. The MA samples on the other hand, were organoleptically acceptable even after a 21-day storage period; the counts had increased only 2 log cycles and the fillets did not seem spoiled. At all the incubation conditions, the counts obtained from the MA-stored fillets were consistently lower than counts from air control samples at days 7 and 14 (table 1).

Within both the air control and MA sample counts, the plates incubated in MA consistently yielded lower initial counts than plates incubated in air at the same temperature. As storage proceeded, counts obtained from MA plates increased slightly more rapidly than for air-incubated plates. At the end of the storage periods, the MA- and air-incubated plates at the same temperature gave roughly similar counts. The counts obtained from air control samples on plates incubated at 35°C revealed an interesting trend. After a sharp, 3 log cycle increase within the first 7 days of storage, the counts actually declined over the next 7-day period. The above results show explicitly that high carbon dioxide concentrations are effective in inhibiting or retarding microbial growth.

Identification studies were carried out on day 0 isolates obtained from all incubation conditions, except 4°C in MA which consistently gave $\leqslant$1.0 x 10^3 counts per gram of fillet. The compositions of the bacterial population were consistent with previous reports on the microflora of fresh seafood. The *Pseudomonas* spp., *Moraxella* spp., *Acinetobacter* spp., and *Arthrobacter* spp. were predominant. Another bacterium which was consistently present could not be readily placed into any of the established genera. This isolate, hereafter referred to as *Aeromonas*-like, exhibited all the characteristics of *Pseudomonas* as outlined by Baumann and Baumann (1979) except that it grew slightly anaerobically. Lower counts of *Micrococcus* spp., Enterobacteriaceae, *Flavobacterium* spp., *Lactobacillus* spp., and *Bacillus* spp. were also obtained.

The population of bacteria isolated at 35°C in air consisted predominantly of *Acinetobacter, Micrococcus* spp., Enterobacteriaceae, and *Lactobacillus* spp. (table 2). The *Pseudomonas* spp., *Moraxella* spp., and *Bacillus* spp. were present in lower amounts. The fillets purchased from Santa Rosa also carried *Staphylococcus* spp. which was coagulase-negative and comprised 4% of the 35°C (air) isolates. The composition of the bacterial populations isolated at 20 and 35°C under MA and 35°C under anaerobic conditions were similar to that of populations isolated at 35°C in air. The differences were in the appearance of *Proteus* spp. and the disappearance of *Pseudomonas* spp.

The bacteria isolated from fillets held under MA for 21 days were limited to isolates obtained from aerobically and anaerobically incubated plates. The isolates from 4 and 20°C in air were about 70% *Lactobacillus* and the remaining were the *Aeromonas*-like isolate (30%). The 35°C plates incubated both in air and anaerobically yielded almost exclusively *Lactobacillus* (table 3). These results indicate that, either directly or indirectly, storage under MA selects for *Lactobacillus* and this *Aeromonas*-like isolate. In a recent conference, Lee (1981) reported similar observations except that he found *Alteromonas putrefaciens* instead of the *Aeromonas*-like bacteria.

Except for the *Staphylococcus* isolated from the fillets from Santa Rosa, none of the pathogenic bacteria associated with marine environments was found. These include *Vibrio parahaemolyticus, Clostridium* spp., and *Yersinia enterolytica*.

Based on the enumeration and identification studies, enumeration and isolation of microorganisms present on seafood samples stored under MA at 4°C should be carried out at 20°C in air. At 20°C in air, the plate counts were the highest of any of the conditions examined and the greatest diversity of bacterial types was found. Also isolates grew rapidly enough so that the plates could conveniently be counted after only 2-3 days.

Lactobacillus and the *Aeromonas*-like isolates from fish stored 21 days under MA were found to grow more slowly under MA than air. The growth rates of three *Aeromonas*-like strains isolated from 21-day MA storage were compared with those of three *Aeromonas*-like strains isolated from "fresh" fish. All three of the 21-day isolates grew more rapidly under MA. This was true even if the inocula were preincubated in air. This result strongly suggests that selection for faster growing variants is occuring during MA storage.

Table 1

Bacterial Counts on Rock Cod Fillets Stored at 4°C in the Modified Atmosphere (MA) (80% CO_2/20% Air)

	Log Standard Plate Count Per Gram											
	Sample I				Sample II				Sample III			
Incubation of isolation plates	Day 0	Day 7	Day 14	Day 21	Day 0	Day 7	Day 14	Day 21	Day 0	Day 7	Day 14	Day 21
Air, 4°C	5.2	6.8	7.4	8.2	5.1	4.8	5.4	6.4	3*	4.7	5.7	6.3
Air, 20°C	5.6	6.5	7.5	8.3	5.3	5.1	5.7	6.6	4.4	5.0	5.9	6.2
Air, 35°C	5.4	6.2	7.2	8.2	4.7	4.8	5.2	6.3	3.9*	4.3	5.4	6.2
MA, 4°C	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3
MA, 20°C	4.0*	6.1	7.2	8.4	4.5	4.8	5.7	6.7	3*	4.6	5.6	6.3
MA, 35°C	5.0*	5.0	5.5	5.6	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3	⩽3
Anaerobic, 35°C	4.2*	5.8	7.2	8.2	3.7*	4.3*	5.1	6.5	⩽3	⩽4	5.3	6.1

* Estimated standard plate count

Table 2

Microbial Flora of Fresh Rock Cod Fillets Obtained from a Retail Outlet

	Percentage of Isolates Identified					
	Incubation Condition of Isolation Plate					
Microbial Group	Air, 4°C	Air, 20°C	Air, 35°C	MA, 20°C	MA, 35°C	Anaerobic 35°C
Pseudomonas Type I	10	4	4	0	0	0
Pseudomonas Type II	10	2	0	0	0	0
Pseudomonas Type II	15	14	6	0	0	0
Aeromonas	0	0	0	0	28	0
Aeromonas-like	4	8	0	0	0	0
Acinetobacter	28	24	17	10	0	0
Moraxella	18	10	0	0	0	0
Flavobacter	0	4	0	4	0	0
Cytophaga	2	8	0	0	0	0
Arthrobacter	6	9	0	0	0	0
Micrococcus	7	10	36	0	0	0
Bacillus	0	3	7	0	0	0
Lactobacillus	0	0	14	6	9	9
Enterobacteriaceae	0	2	13	--	--	--
Enterobacter	nd	nd	nd	30	48	80
Citrobacter	nd	nd	nd	32	4	7
Proteus	nd	nd	nd	16	11	0
Others	0	2	3	2	0	4
No. of isolates identified	200	204	156	100	84	55

Table 3

Microbial Composition of Rock Cod Fillets Stored for 21 Days Under Modified Atmosphere (MA) (80% CO_2/20% Air)

	Percentage of Isolates Identified				
	Incubation Condition of Isolation Plate				
Microbial group*	Air, 4°C	Air, 20°C	Air, 35°C	MA, 20°C	Anaerobic, 35°C
Aeromonas-like	31	28	0	0	0
Lactobacillus	69	69	98	100	100
Yeast	0	2	0	0	0
Others	0	1	2	0	0
No. of isolates identified	105	105	105	105	105

* Identification methods used would have detected all microorganisms listed in table 1.

References

Baumann, P. and Baumann, L. 1979. The Marine Gram negative Eubacteria. In *The Prokaryots*, M. P. Starr, H. Stolp, H. G. Truper, A. Balows and H. G. Schelgel, eds. Springer-Verlag, New York, Heidelberg, Berlin.

Lee, J. S. 1981. Selection and growth of seafood microorganisms under a carbon dioxide environment. Presented at the Conference on Modified and Controlled Atmosphere Packaging of Seafood Products, San Antonio, Texas, January, 1981.

Publications

Johnson, A. 1981. Modified atmosphere storage of seafoods. Hornblower 34:10-11.

Johnson, A., Parkin, K., Ogrydziak, D., and Brown, W. D. 1981. Seafood storage in modified atmosphere. Conference on modified and controlled atmosphere packaging of seafood products, San Antonio, Texas, January 1981.

Mokhele, K., Johnson, A. R., Barrett, E., and Ogrydziak, D. M. (Submitted) 1982. Microbiological analyses of rockcod (*Sebastes* spp.) stored under elevated carbon dioxide atmospheres.

Ogrydziak, D. M. and Brown, W. D. 1981. Modified atmosphere storage of seafoods: temperature effects. Refrigerated and frozen foods division program, Institute of Food Technologists Annual Meeting, Atlanta, Georgia, June 1981.

Ogrydziak, D. M. and Brown, W. D. 1982. Temperature effects in modified-atmosphere storage of seafoods. Food Technology 36:86-88, 90, 91 and 92-96.

CHITIN WASTE UTILIZATION

University of California, Davis
R/F-70
1980-81

Paul A. Carroad and David M. Ogrydziak

The project extends projects R/F-34 (Bioconversion of Chitin Wastes) and R/F-50 (Genetic Improvement of a Chitinase-Producing Microorganism) as a combined project. The project had several related goals. One goal was to design and conduct a feasibility analysis of a shrimp waste treatment process for the bioconversion of chitinous shell material to a useful product (single-cell protein). More specifically this involved completion of the preliminary design and economic analysis of the process by incorporating recently developed data on waste pretreatment. Other goals included completion of work on strain development of a chitinase-overproducing microorganism and investigation of the possibility of using recombinant DNA techniques to substantially increase the production of a chitinase enzyme system by *Serratia marcescens*.

In the bioconversion process, shrimp processing waste is pretreated by size reduction, deproteination, and demineralization to yield a material suitable for bioconversion. Protein can be recovered by precipitation. Some pretreated chitin is used as substrate for microbial chitinase production. The bulk of the pretreated chitin is mixed with the chitinase to hydrolyze the chitin to the monomer N-acetylglucosamine. The hydrolysate sugar solution serves as substrate for production of yeast single-cell protein.

Within this project it was determined that size reduction to the 20 mesh to 60 mesh range was sufficient to yield significant protein extraction in 60 minutes. Deproteination was accomplished at pH 11.5 and 30°C. Demineralization was best accomplished with 100 g chitin per liter of 8% HCl at 30°C in 8 hours. Eighty percent conversion of chitin so pretreated could be achieved in 24 hours. Fermentation experiments on pretreated chitin identified the most favorable conditions for enzyme production as 27.9°C, pH 7.64, based on response surface methodology analysis. A general kinetic model of growth and enzyme production was fitted to the data.

The overall mass balance results for the process design are shown in figure 1. The design basis is 1,670 kg dry waste per day. The design was predicated on current results and those of Sea Grant project R/F-34. Process equipment and operating costs were based on published correlations. Product value was related to fish meal on an equivalent protein basis. An after-tax cash-flow analysis shows a negative cash flow from the process of $0.062 per kg of wet waste. The new present value of the process is negative, as expected for a pollution treatment process whose by-product value does not offset process costs. Increase in product value, substitution of cheaper construction materials than stainless steel, and changes in federal tax policy may allow closer approach to the current break-even point.

Characterization of the chitinase-overproducing strain IMR-1E1 of *Serratia marcescens* was completed. This strain in shake flasks produced about three times as much as the wild type of the enzymes of the chitinolytic enzyme complex. However, in the 14-liter fermentor the increase in enzyme production was significantly lower. This was shown to be due to reversion of the IMR-1E1. If the high levels of chitinolytic activity are due to gene duplication, then this would explain instability of chitinase production and IMR-1E1 might be stabilized by genetic means.

There was significant progress in the investigations of the possibilities of using recombinant DNA techniques to make a chitinase-overproducing *Serratia marcescens*. The major problem of how to reintroduce plasmid DNA into *S. marcescens* was solved by development of a transformation procedure. The *S. marcescens* strain used in the chitinase studies could not be transformed with pBR322 using the standard transformation procedures used for *Escherichia coli*. Heat shocking the cells before transformation and selecting for high levels of ampicillin resistance solved the problem. Evidence for transformation is shown in figure 2. Plasmid (pBR322) DNA was extracted from *E. coli* and presumed *S. marcescens* transformants. The DNA was digested with the restriction endonuclease *HaeIII* and the same number and size of restriction fragments were produced (lanes g and h). Plasmid stability and copy number were similar in *E. coli* and *S. marcescens* and the plasmid could be amplified by inhibiting protein synthesis. One problem encountered was that hybrid plasmids of pBR322 with *S. marcescens* DNA inserts were not stably maintained in *S. marcescens*. This most likely indicates a restriction enzyme system in the *S. marcescens* strain which would have to be removed genetically.

Attempts at cloning genes of the chitinase enzyme complex were unsuccessful but suggested alternative procedures and yielded insights into *S. marcescens* physiology. Partial digests of *S. marcescens* DNA were ligated into the various restriction sites of pBR322 and the hybrid plasmids transformed into *E. coli*. Several thousand transformants (with *S. marcescens* DNA inserts) were screened for endochitinase activity (clearing of chitin impregnated agar plates) and for chitobiase activity (cleavage of p-nitrophenyl-N-acetyl-β-D-glucosaminide [NPglu], an analogue of chitobiose). One transformant which cleaved NPglu was found, but the NPgluase activity was inactive against chitobiose. However, the chitobiase activity of *S. marcescens* was active against NPglu. Based on the size of the *S. marcescens* DNA inserts, sufficient transformants were screened so that chances of not finding the chitinase genes were less than 20%. Obviously, more transformants should be examined. However, perhaps the chitinase gene products are lethal to *E. coli* or *E. coli* cannot secrete them. Alternative *E. coli* hosts and plasmids and cloning directly into *S. marcescens* (when a restrictionless strain is obtained) should be considered.

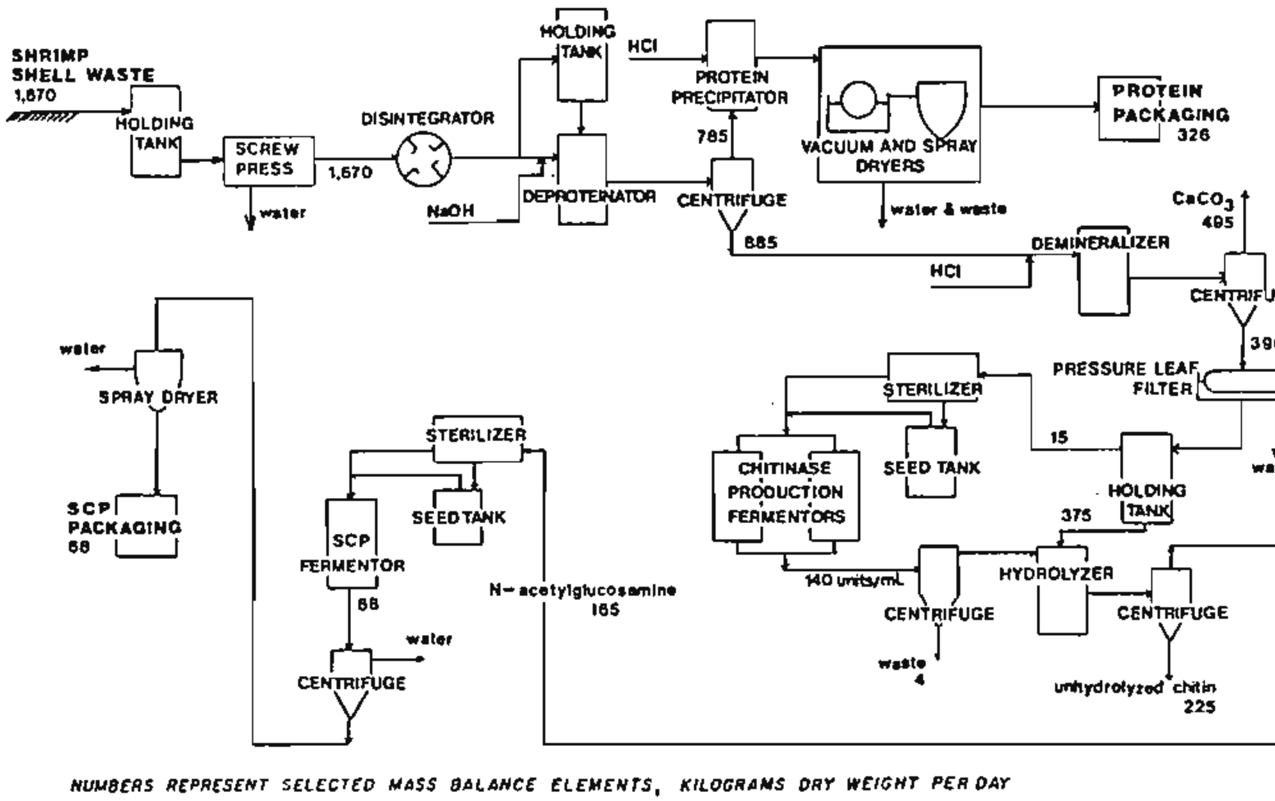


Figure 1. Process flow chart and chitin mass balance for bioconversion scheme.

Figure 2. Transformation of *S. marcescens* QMB1466 with plasmid pBR322. Restriction endonuclease digests of plasmid DNA were fractionated on a 7.5% polyacrylamide gel. Plasmid DNA from RR1 transformed with pBR322 (lanes a, d, f, and h) was prepared by CsC1-PdI density gradient centrifugation. Plasmid DNA from QMB1466 transformants (lanes c, e, and g) was prepared by the miniscreen procedure. Lanes a, g, and h are *Hae*III digests, lanes c, and d are *Eco*RI digests, lanes e and f are *Eco*RI and *Sal*I double digests, and lane b is phage λ digested with *Hin*dIII (BRL) as a molecular weight standard.

Cooperating Organizations
Canada Packers Co., Ltd.
University of California Agricultural Experiment Station

Publications

Reid, J. D. and Ogrydziak, D. M. 1981. Chitinase-overproducing mutant of *Serratia marcescens*. Appl. Environ. Microbiol. 41:664-669.

Reid, J. D., Stoufer, S. D., and Ogrydziak, D. M. In press. Efficient transformation of *Serratia marcescens* with pBR322 plasmid DNA. Gene.

Revah-Moiseev, S. and Carroad, P. A. 1981. Conversion of the enzymatic hydrolysate of shellfish waste chitin to single-cell protein. Biotechnology and Bioengineering 23(5):1067-1078.

Tom, R. A. and Carroad, P. A. 1981. Effect of reaction conditions on hydrolysis of chitin by *Serratia marcescens* QMB1466 chitinase. J. Food Science 46(2):646-647.

Young, M. E. and Carroad, P. A. 1981. Dependence of extracellular chitinase activity of *Serratia marcescens* QMB1466 on continuous culture dilution rate. Canadian J. of Micro. 27(1):142-144.

Young, M. E., Carroad, P. A., and Bell, R. L. A mathematical model for chitinase production. Second World Congress of Chemical Engineering, Montreal, Canada, October 1981.

WATER CONSERVATION AND POLLUTION ABATEMENT IN SEAFOOD PROCESSING THROUGH WATER RECYCLING

University of California, Davis
R/F-71
1980-82

Paul A. Carroad and Robert J. Price

The mechanical processing of Pacific shrimp currently demands huge quantities of water, on the order of 25 to 40 gallons per pound of finished product in the peeling operation alone. Supplying this water not only consumes a valuable resource from community reservoirs or from private wells, but also contributes to high flows of polluted effluent and is consumptive of energy. The 13 million pounds of shrimp processed in California in 1978 required between 65 and 100 million gallons and contributed as much polluted effluent. The economic consequences of excessive water use are at least twofold, leading to expense for both water supply and for eventual treatment. Environmental restrictions may further increase the need to reconsider processing methods to reduce effluent flows.

The overall objective of this project was to assess the technological and economic feasibility of incorporating water recycling in shellfish processing plants to achieve water conservation and pollution abatement while maintaining product quality. The specific goals of this project were to 1) collect data from several shrimp processing plants on water use and other processing parameters; 2) select one plant for a detailed study involving installing water-flow monitoring devices and sampling and analyzing water and product to determine water use, microbial load, and other significant parameters; 3) evaluate processing data to suggest water-recycling design alternatives which would reduce water use and volume of effluent; 4) select a processing plant in which one or more lines could be modified for water recycling and test the proposed recycling system under operating conditions to provide necessary comparative data on product quality, water flows and quality, and on confirmation of design alternatives; and 5) perform an engineering and economic feasibility evaluation to provide specific design recommendations to the seafood processing industry for water conservation and pollution abatement.

The 10 Pacific shrimp processors in California were surveyed by mail to obtain data on water use, processing paramenters, and production volumes. This survey was followed by an on-site inspection of eight major processing plants to obtain more detailed data on water use, shrimp processing equipment design and installation, and plumbing configurations. Processors were consulted for current ideas and redesign concepts undertaken or envisioned to reduce water use in mechanical shrimp processing. Data obtained from the survey, on-site inspections, and consultations with processors will be used in phase two of this project to evaluate water-recycling design alternatives.

A large Sacramento-based shrimp processing plant, Meredith Fish Company, has been selected for detailed processing studies. This plant was selected based on the promised cooperation of the processor, on its logistical convenience, and, most importantly, because the plant operates eight mechanical shrimp peelers in two banks of four each. With this processing operation, it would be possible to modify one set of four peelers to recycle water and to obtain comparative data simultaneously on the modified and unmodified systems.

Water pipes supplying fresh water to four of the shrimp processing machines and waste water pipes have been modified to contain pilot tubes. These tubes are in-line devices that yield a differential pressure proportional to water flow rate. The differential pressure was measured on a transducing meter. Flow rates in open flumes were monitored volumetrically. Water flow rates were monitored during peak shrimp processing periods, and a water-flow balance was determined based on average flow measurements. Water samples taken during water-flow monitoring operations were analyzed for residual chlorine and microbial load. Shrimp samples, before and after processing, were also examined microbiologically. The results of these analyses formed the basis for further studies on recycling design alternatives.

A typical shrimp processing plant with four peeling machines may process about 1,720 pounds of Pacific shrimp (*Pandalus jordani*) per hour. At this processing rate, water use may be about 264 gallons/minute (gpm). Our data indicates that Laitram PCA mechanical shrimp peelers can be adequately operated using only 38 gpm, although 45 gpm is more practicable. When compared to the 66 gpm per machine often used by shrimp processors, this represents a saving in fresh and waste water of about 42%.

The bacterial counts of shrimp before processing averaged about 500,000 colony-forming units per gram. These counts are evidently the result of a lag time of about 2 days between harvesting and processing. This lag time increases the water holding capacity of the shrimp meat and improves shrimp meat recovery. Precooking by live steam for about 2 minutes results in a reduction in bacteria counts by one to two log cycles. Mechanical action and fluming cause a further reduction in bacterial counts.

Conveying cooked shrimp through simulated flume systems of various configurations showed similar reductions in the bacterial load of the shrimp meat. When the shrimp were passed through the same flume configuration several times (equivalent to repeatedly fluming the shrimp in 30-foot segments over several hundred feet), some differences in reductions were observed. When fresh flow or countercurrent configurations were used, there was a 25% greater decimal reduction in bacterial load than if co-current recycling was used. When the water source for the co-current systems was chlorinated to a residual of about 8 ppm, there was a 25% greater decimal reduction when compared to fresh flow or countercurrent methods without chlorination. Based on these data, a countercurrent recycling system using chlorinated water would probably provide the greatest reduction in bacterial load on the shrimp meat.

When a typical shrimp processing plant employing four mechanical shrimp peelers was theoretically modified to incorporate water conservation and recycling, a substantial reduction in water use was observed. Capital expenditures to install a countercurrent recycling system would include the purchase of about 50 feet of sanitary pipe, two or three pumps, a chlorinator, and perhaps a small tangential screen. Water use would theoretically be reduced from 264 to 152 gpm, a reduction of about 42%. For a plant processing one million pounds in a 6-month season, the total savings resulting from water conservation and recycling modifications would be between $1,400 and $4,500 depending on municipal water and sewer rates.

An initial goal of this project was to install a recycling system in a commercial shrimp processing plant and to test this system under commercial operating conditions. Questions raised by processors and public health officials concerning the potential for public health problems resulting from a possible build-up of pathogenic microorganisms in recycled flume water prevented this goal from being achieved. In our study, low numbers of fecal coliforms and coagulase-positive staphylococci were found on finished shrimp meat. The source of these bacteria is probably the final hand-sorting operation, usually done by workers without gloves because of the dexterity required to remove the defects from the small Pacific shrimp. Studies on the occurrence, source, and fate of pathogenic bacteria in mechanical shrimp processing is continuing.

Cooperating Organizations

California Seafood Institute
Castle Rock Seafoods
Crescent Fisheries
Eureka Fisheries
Meredith Fish Company
Nor-Cal Seafoods
Pt. St. George Fisheries
Tarantino Fish Company
Tom Lazio Fish Company
West Coast Crab

Publications

NEILSON, L. A. 1982. Water conservation and effluent reduction by water recycling in Pacific shrimp processing. M.S. thesis, University of California, Davis.

NEILSON, L. A., PRICE, R. J., AND CARROAD, P. A. 1982. Water conservation and effluent reduction by water recycling in Pacific shrimp processing. Pacific Technologists Annual Meeting, March 1982, Sacramento.

NEILSON, L. A., PRICE, R. J., AND CARROAD, P. A. 1982. Water conservation and effluent reduction by water recycling in Pacific shrimp processing. Institute of Technologists Annual Meeting, June 1982, Las Vegas.

VITAL STATISTICS OF THE FEMALE STOCK OF DUNGENESS CRAB (*CANCER MAGISTER*) IN NORTHERN CALIFORNIA

Humboldt State University
R/F-72
1980-82

David C. Hankin

The overall project objective for this study is to obtain an adequate field-supported description of the vital demographic statistics of the female stock of dungeness crabs in northern California. To develop this description, we have identified the following components: female growth curve, fecundity-size relationship, female age composition and abundance, and female survival rates.

Female Growth Curve

Development of a growth curve for female crabs requires collection of data necessary to establish molt increments (given initial size) and molt frequency. Our study has used a dual approach to collection of these data: 1) an ocean tag-recovery program and 2) laboratory-generated data concerning molt increments and molt frequency.

Ocean Tag Recovery

During the period 1 October 1980 to 1 October 1981, substantial progress toward this objective was made. In field activities nearly 5,000 adult female crabs were measured, tagged with a FLOY anchor tag at the crab carapace suture line, and released off Trinidad and Eureka, California for subsequent recovery by commercial fishermen. As of 1 October 1981, about 100 tags had been returned; of these about 30 had molted prior to capture, thus generating desired molt increment data. We expect perhaps another 100 crabs (all molted) to be returned during the early 1981-82 crab season.

In the first two project years we tagged a total of 9952 adult female crabs (versus a goal of 10,000) and received a total of about 400 tag recoveries (for a recovery rate of about 4% versus an anticipated recovery rate of about 2%). Of the total recoveries, about 120 have molted, giving us needed data on molt increments and molt frequency. At least one recovery has been a definite double molt, giving clear proof that the FLOY anchor tags which we are using can hold through more than one molt. In addition, length-frequency data have been collected for about 12,000 adult females during the first 2 project years, and we have developed a modified crab trap design which allows us to sample all adult female sizes without selection problems. Crab trap gear selection work is further discussed in the Female Age Composition, Abundance, and Survival Rates section.

Laboratory Studies

Laboratory experiments designed to generate molt increments and to evaluate possible effects of tagging on molt increments were of two types. First, crabs were held and fed for several months, with and without tags applied, in an elegantly designed statistical array in large aquaria at the Humboldt State University (HSU) marine laboratory. The intention of these experiments was to generate molt increments among tagged and untagged crabs held under controlled laboratory conditions. Second, female crabs were removed from premating embraces during sampling on board the contracted commercial vessel. These crabs were returned to the HSU marine laboratory, measured, and subsequently measured after molting took place within 1-4 days. Of the two approaches, only the latter proved successful in generating useful molt increment data. Female crabs held for long periods of time in the laboratory failed to molt when the peak of natural molting activity occurred; perhaps 3 or 4 out of 100 animals had molted in this experiment by the apparent end of natural molting in the ocean. In addition, there was an unacceptable (although low) level of mortality for crabs in these groups. In contrast, at least 50 useful observations on molt increments were obtained from those females removed from premating embraces and returned to the laboratory.

Both molt increments from recovered tagged crabs and from females removed from premating embraces showed a slight but significant decline in size with increasing initial crab size. As crabs removed from premating embraces would presumably show the least possible "laboratory effect" on generated molt increments, molt increments from this group of crabs may be logically compared with molt increments from recovered tagged crabs. Such a comparison has revealed no detectable tagging effect; molt increments for recovered tagged female crabs have fallen along the same line as for those generated in the laboratory from females removed from premating embraces. Our tentative conclusion is that application of the tags produces no detectable effect upon subsequent molt increments. During the first 2 project years, a total of 186 molt increments have been generated from female crabs ranging in carapace width from about 30 to 160 mm.

In addition, laboratory studies have examined tag retention rate and possible loss of tags due to physical abrasion by adult males during actual mating activities. These studies have indicated a fairly high tag-retention rate through one molt (about 85%) and have failed to suggest that mating activities result in any statistically significant tag retention differential when females which molt in the absence of males are compared to females which molt in the presence of males.

Tentative Conclusions — Female Growth Curve

Statistical comparison of regression lines for molt increment versus initial crab carapace width for tag-recovery data and laboratory-generated data has failed to show a significant difference in molt increments between field and laboratory crabs. Tag retention rates are apparently quite high and are not influenced to a significant extent by mating activities; however, there is probably greater loss of tags by crabs that molt than by crabs that fail to molt.

For both field- and laboratory-collected data, molt increment shows a statistically significant decline with increasing initial female crab carapace width. Variance about the regression line appears quite constant. On the basis of initial analyses of tag-recovery data, it appears that molt frequency declines with crab age (or size), and there are indications that female crabs may have a terminal molt. However, interpretation of collected data for estimation of molt frequency is fraught with difficulties caused by gear selection, by biased recoveries by commercial fishermen, and by an unknown but probable differential tag retention between molted and nonmolted recoveries. These topics are further addressed in the Female Age Composition, Abundance, and Survival Rate section. Statistical analyses of laboratory-generated molt increments between the first 2 project years have shown no significant difference in molt increments across these 2 years.

Fecundity-Size Relationship

Ocean sampling for purposes of collecting berried female crabs (for egg-mass fecundity measurements) did not take place until 1 January 1981. Unfortunately, hatching of egg masses and release of larvae took place abnormally early during 1980-81. By mid-January berried females were no longer usual and those few found were at too advanced a stage in development to warrant fecundity determinations. As a result, no fecundity determinations were made during 1980-81; instead, an undergraduate student performed an exhaustive literature review of crustacean fecundity measurement. This information will be used to develop our procedures for the 1981-83 sampling periods.

Although fecundity determinations were not made during the first project year, a total of nearly 40 adult females carrying full egg masses was collected during December and early January of 1981-82. Of these crabs, a total of 34 allowed subsequent valid estimation of fecundity. Techniques for preservation and processing of dried female crab egg masses and for statistical subsampling were developed and refined during this past year and then successfully applied to fecundity estimation. Females ranged in size from about 130 to 165 mm, and total estimated fecundities ranged from about 500,000 to 1,500,000, similar to figures that have been reported in the literature. However, we found no statistically significant relationship between female crab fecundity and initial female size. Collection of females during the third project year will be revised in an attempt to discover the possible reasons for this apparent lack of dependence of fecundity on crab size and to determine if this result is real or an artifact of sampling or collection procedures. We are confident that our point estimates of total fecundity are good.

Female Age Composition, Abundance, and Survival Rates

Determination of the age composition of the female stock of dungeness crab in northern California requires knowledge of size at age, molt frequency, and gear selection. The tag-recovery program and related laboratory studies should give us adequate estimates of size at age and molt frequency, although molt frequency estimation is an extremely difficult problem. Molt frequency is usually estimated from tag recoveries. However, analysis of tag-recovery data is complicated by at least the following confounding factors:

1) The commercial crab traps, which are the primary recovery gear, are highly selective for larger female crabs. Hence, for female crabs tagged at a small initial size, there is positive bias for recovery of these animals that *have* molted; retention rates for crabs that have *not* molted will be much lower.
2) If crabs that molt have a lower tag retention rate than do crabs that do not molt, then recoveries are biased toward animals that do not molt.

Interestingly, our search of the crustacean literature regarding determination of molt frequency has suggested that neither gear selection nor relative tag retention rates have been considered in previous molt frequency estimation contexts. This we hope to rectify. We have had excellent success with determination of the selection curve for our initial experimental crab trap gear. This year we will use our modified nonselective gear to determine the selection curve for commercial crab traps with open escape ports and large mesh.

We now have the MacDonald-Pritcher FORTRAN computer program for separation of distribution mixtures on line on the Humboldt State University (HSU) CYBER computer. Preliminary analyses using this approach have shown good promise for eventual successful separation of age (or size) groups, but they have also shown that assumptions regarding the pattern of variance with age are critical. Until we are satisfied that we have achieved reasonable separation of component groups in our length-frequency data, we will not attempt estimation of female abundance or survival rates.

Other Project Activities

We held a 2-day dungeness crab workshop in November 1980. This successful get-together of dungeness crab researchers, partially supported by the Pacific Marine Fisheries Commission, was described in the 1980-82 (second year) renewal proposal of our Sea Grant project.

A drawing was held in October 1981 with a $500 reward for the fisherman who had returned the tagged crab whose tag was selected in the drawing. This technique appears to have two advantages over more standard reward systems that pay fishermen for returned tags: 1) administrative paperwork necessary to process unknown numbers of recoveries is eliminated, and 2) a substantial, rather than trivial, inducement for returning tags (albeit an uncertain reward) is created. The return of tagged crabs has been promising thus far.

The project was successfully publicized in several different ways. The principal investigator was interviewed on television about the project and its goals. Project-related information was disseminated to local fishermen through the area Sea Grant Marine Advisory publication, *Coastal Currents*, and the Humboldt Fishermen's Marketing Association newsletter. Brief presentations were given in Crescent City and Eureka before commercial fishermen by a Sea Grant trainee and the principal investigator.

In September 1981, the principal investigator and one Sea Grant trainee traveled to the Pacific Biological Station, Nanaimo, B.C., and had a lengthy and helpful discussion with Terry Butler. Mr. Butler is in the process of writing a book on the biology and management of the dungeness crab and has expressed excitement at our new findings concerning the basic life history of female dungeness crabs. Our work, although in a preliminary form, will probably be presented in his upcoming book. This past June, the principal investigator delivered a talk on his previous modeling work (McKelvey *et al.*, 1980) at the National Marine Fisheries Service (NMFS) Tiburon Laboratory. This talk resulted in an extremely lengthy discussion and was a worthwhile project activity.

A reply to L. Botsford's comment concerning the role of cannibalism in dungeness crab dynamics was published in the October 1981 issue of the *Canadian Journal of Fisheries and Aquatic Sciences*. In part, this reply utilizes project information developed during the 1980-81 year.

Cooperating Organizations
California Department of Fish and Game
Humboldt Fishermen's Marketing Association
KVIQ, Eureka
Pacific Biological Station, Nanaimo, B.C.
Pacific Marine Fisheries Commission

Publications

McKELVEY, R. AND HANKIN, D. 1981. Reply to comment on cycles in the northern California dungeness crab population. Can. J. Fish. Aquat. Science 38(10):1295-1297.

EVALUATION OF THE EXPERIMENTAL ABALONE ENHANCEMENT PROGRAM

University of California, San Diego
R/F-73
1981-82

Mia J. Tegner

A small-scale red abalone (*Haliotis rufescens*) seeding experiment was concluded at Palos Verdes this year. Large seed were used in this experiment (499 averaging 70 mm and 175 averaging 45 mm) because of Japanese results suggesting that survivorship of seeded abalones levels off above 40 mm and because the thicker shells of the larger animals, which are rarely destroyed by predators, would give us a better understanding of sources of mortality.

Shells were collected monthly, and 1 year after the abalones were seeded, the entire 625-m^2 site was sampled for live animals and cryptic shells. We recovered six (or 1.2%) of the larger seed and two of the smaller seed alive, a 1.1% recovery rate. Based on the collection of shells, 42% of the larger seed and 34% of the smaller seed were known to be dead.

The size-frequency distribution of growth of the recovered shells shows that about half did not grow at all and that mortality rates apparently decreased considerably as the animals grew. Thirty-two percent of both types of seed and 38% of the native shells found within the site were drilled by *Octopus* spp. This underestimates the importance of octopus predation because these animals do not drill all their prey. Spiny lobsters, *Panulirus interruptus*, and sheep crabs, *Loxorhyncus grandis*, are also known to prey on abalones and about one-third of all the shells had the chipped edges characteristic of crustacean predation. A live animal found 10 m from the site and shells up to 50 m away suggest that the unaccounted for animals have dispersed over a large area.

A comparison of seed mortality with that of native red abalones in the same area has general implications for the recovery of red abalone populations on the Palos Verdes Peninsula. The number of native red abalones in the planting area was estimated in preseeding surveys and native shells were collected along with those of the seed abalones during the year-long study. Based on those numbers, the mortality of native red abalones was 69%. The native red abalones averaged 28 mm at the start of the experiment, and the greater susceptibility of smaller animals to predation doubtlessly contributed to the higher mortality rate than that observed for the hatchery-reared animals. Nevertheless, these results suggest that predation, especially by octopuses, and not lack of recruitment is limiting the recovery of red abalone populations at Palos Verdes. Forty octopuses were removed from this area over the course of the year.

We had hoped to test the hypothesis that appropriate nursery habitat enhances the survival of seeded abalones as well as the settlement and survival of native abalones on artificial reefs near Camp Pendleton. When eight reef modules were constructed by Southern California Edison in 1980, four were "iced" with appropriate sized rocks to provide nursery habitat for juvenile red abalones. We assisted the Department of Fish and Game in seeding two of each type of reef with red abalone seed in 1981. Unfortunately, the kelp transplants to the reefs have not been successful so there has been virtually no food for the abalones. The few abalones found 4 and 6 months after planting exhibited little or no growth and had shrunken tissues and badly encrusted shells — all indications of poor physiological conditions. It appears likely that most of the animals starved.

We concluded our drift bottle study of the dispersal of green abalone (*H. fulgens*) larvae in the southern California bight. Twelve hundred drifters were dropped during each of the two peaks of the green abalone breeding season over the eight major past and present green abalone beds in the state. The directions of transport varied with seasonal current patterns but the general conclusion remained the same. Less than 4% of the drifters released near Channel Island populations were later recovered on the mainland and of these, less than 7% were within the green abalone larval life span; most were recovered considerably later. We conclude that successful larval dispersal from the Channel Islands to the mainland is relatively rare. On the other hand, a high proportion of the drifters released over green abalone beds along the coast were found several kilometers away along the coast within time periods appropriate for larval colonization. There was minimal transport between isolated mainland sites; for example, only 1 drifter out of 134 recovered on the Palos Verdes Peninsula was from another mainland site (and 1 was from Santa Catalina Island). Thus, while an isolated area such as Palos Verdes is likely to receive a few green abalone larvae from distant spawning populations, the short larval life and coastal current patterns suggest that endemic sources of larvae would be much more important.

The California Legislature closed much of the Palos Verdes Peninsula to all abalone fishing in 1977 to give seriously depleted stocks a chance to recover. The drift bottle results suggest an explanation as to why green abalone populations are responding very poorly to this closure. In order to provide a source of larvae, 4,400 reproductively mature green abalones were transplanted into areas of the Palos Verdes Peninsula where the drift bottle results suggest that the probability of larval retention on the peninsula is high. The transplanted abalones appear to have adapted well to their new environment as evidenced by shell growth and gonadal development. Final analysis of broodstock transplantation as an approach to abalone enhancement will depend upon a demonstration of increased natural recruitment in target populations as compared to controls outside the apparent range of the larvae.

In an effort to understand the fate

of hatchery-reared abalones after they are planted in the ocean, we have been comparing the behavior of native and hatchery-reared green abalones in aquaria. The abalones were offered four habitats to choose from which offered different degrees of protection from predators; three of the hatitats were similar to habitats where abalones of various sizes are found in the field. Our results show that native abalones select hatitats differently than hatchery-reared animals of the same size category and that this choice affects their survival. Spiny lobsters were able to consume significantly more of the hatchery-reared abalones of all sizes tested (20 to 50 mm) than natives. These experiments are currently being repeated with red abalones and expanded to very small (5-10 mm) animals to look at the effects of size (and thus length of time in hatchery environment) on behavior.

Cooperating Organizations

California Department of Fish and Game
Doheny State Beach and Los Angeles County lifeguards
Los Angeles County Fish and Game Commission

Publications

LEVIN, L. A. 1982. The roles of life history, dispersal and interference competition in the population and community structure of a dense infaunal polychaete assemblage. Ph.D. thesis, University of California, San Diego.

FIELD EVALUATION OF AN ABALONE ENHANCEMENT PROGRAM

University of California, Santa Barbara
R/F-74
1981-82

R. J. Schmitt and J. H. Connell

Abalone landings in California have decreased sharply throughout the past decade (Richards, 1977). By 1975, the California Department of Fish and Game had initiated programs to ensure the long-term viability of the abalone fishery (Burge *et al.*, 1975). Among the most promising techniques for rapidly revitalizing depleted areas is the outplanting of juvenile abalones reared in hatcheries (Morse *et al.*, 1980). Such a method became feasible when techniques for culturing red abalones (*Haliotis rufescens*) were developed. Accordingly, a joint research program of California Department of Fish and Game and Sea Grant was established to examine the scientific feasibility of enhancing abalone stocks using outplants of hatchery animals. A series of test outplants were conducted independently by a research group at Scripps Institution of Oceanography (directed by Dr. Mia Tegner) and by a group at University of California (UC) Santa Barbara (headed by Drs. R. J. Schmitt and J. H. Connell).

One test planting by the UC Santa Barbara program proved particularly successful in the short term (Schmitt *et al.*, 1981). The planting, initiated in May 1980, involved the transfer of nearly 9,000 juvenile red abalones from the hatchery to a study area near Santa Barbara. The result of careful monitoring of the outplant during the following 17 weeks indicated that juvenile red abalones can be successfully transferred to the field with high survivorship at sizes ranging from 10 to 45 mm shell length (corresponding to approximately 0.5-2.0 years of age). Mortality of the cohort was on the order of 1% per week for the first 17 weeks after planting.

The aim of the current study was to evaluate the performance of this outplant after 2 years. Long-term success is necessary for outplanting to result in an enhanced population of abalones that can be fished; the evaluation of the initially successful outplant at Santa Barbara (Naples Reef) can provide direct information on this crucial topic.

In May 1982, 2 years after outplanting 9,000 juvenile red abalones, the experimental and control sites were revisited and abalone density determined. Abalones were placed into two categories based on size, juveniles (≤80 mm shell length) and adults (>80 mm) (see Young and DeMartini, 1970; Giorgi and DeMartini, 1977). Juvenile abalone density was estimated from four permanent transects each 20 m^2 in each of the control and experimental (where animals were planted) areas.

The results, summarized in table 1, illustrate the following pattern. Juvenile abalones were relatively scarce before the planting was conducted. However, 17 weeks after outplanting, the experimental area displayed a significantly greater density of juvenile abalone compared with the control site. ANOVA revealed that only the experimental site displayed a significantly greater density (the significant time x site interaction), indicating that our outplant was responsible for the greater density at 17 weeks. The slightly higher (but nonsignificant) density of juvenile abalones in the control site at 17 weeks can be attributed to the migration of outplanted abalones into the area.

A posteriori comparisons of cell means for juvenile abalone density (table 1) reveal an important pattern through time. In the control site, none of the estimates for juvenile density differed through time (before planting versus after 17 weeks versus after 2 years). The situation in the experimental area was a significant increase in juvenile abalone density 17 weeks after outplanting. However, there is no difference in the abundance of young abalones in the experimental site 2 years after planting compared with the density either immediately before the test plant or at 17 weeks after the test planting was done (table 1).

There are several explanations for such a pattern. All assume that natural recruitment of abalones was relatively low subsequent to the planting. First, juveniles outplanted could have grown out of the juvenile size class into adults (i.e., grown past 80 mm shell length). This is a likely explanation if growth rates of juveniles were on the order of 20-30 mm/year, as the average size outplanted was nearly 18 mm. This result, of course, is that desired to demonstrate that ouplanting will enhance adult abalone stocks. Second, outplanted animals could have emigrated out of the study area. We attempted to minimize this possibility by systematically searching a wide area surrounding the study site (roughly 200 x 200 m). Finally, the outplanted juveniles could have died. These possibilities are addressed later.

It is not clear whether the live juvenile red abalones found after 2 years in the study area were those we outplanted. The average size of juveniles found in May 1982 was 24 mm, barely 6 mm greater than the average size at planting. However, we found that survivorship during the first 17 weeks was inversely related to size at time of outplanting; by far the highest initial mortality was in larger abalones whereas the smallest sizes (8-10 mm) showed the lowest initial mortality. Assuming that only the smallest of the abalones outplanted survived, their growth increment would still only be about 7 mm per year. This figure is well below that expected based on field and laboratory growth studies (Leighton, 1974; Tutshulte, 1976).

It seems unlikely that many of the juvenile abalones we observed in May 1982 were individuals outplanted in May 1980. Most of the juvenile red abalones observed in May 1982 were probably individuals that recruited subsequent to the outplant. Wide searches of the area surrounding the study site failed to resolve the issue of emigration of outplanted individuals; very few abalones were seen in general.

A direct test of growth into the adult size class (greater than 80 mm shell length) is a vital concern. If adult abundance was greater in the experimental area (but not the control) in May 1982, compared with May 1980, this would be strong support for long-term success of the outplant. However, table 2 shows that adult red abalone density (and density of all other species of abalone) declined from about one per 20 m² in May 1980, to zero in May 1982. Clearly, adults of all sizes at both sites disappeared. Systematic searches of the general area revealed only seven live adult red abalones (in approximately 40,000 m²).

The data described above strongly indicate that the 1980 outplant of juvenile red abalones failed to produce adults or to increase abalone density in general during the 2 years following planting. Of considerable interest is the reason(s) why the planting failed. The marked decline in abundance of adult red abalones can be explained, and in turn suggests why the test plant failed. The most likely explanation for the disappearance of adult abalone is a catastrophic mortality event that occurred following a severe winter storm in 1980. The once-in-a-century storm occurred in late February, just prior to the May 1980 outplant. Swells greater than 6 m in wave height battered Naples Reef and removed a majority of the larger algae (especially *Macrocystis* sp. and *Pterygophora* sp.). Remaining large algae were consumed by sea urchins (*Strongylocentrotus* spp.) that began searching wide areas on the reef for food after the storm. Thus, it seems quite possible that adult (and outplanted juveniles) died from starvation. These patterns of algal abundance and sea urchin activity following the storm have been (and continue to be) investigated by Dr. A. Ebeling of UC Santa Barbara.

Two observations support the starvation hypothesis. First, a large number of intact shells of adult red abalones accumulated in the study area during the 2-year period following outplanting. Table 3 lists the size-frequency distribution of these shells collected from the study area. The mean size of adult shells was 146 mm, which matches well with the average size of live adult abalones (148 mm) found at Naples Reef in May, 1980. Second, the seven live abalones encountered at Naples Reef were collected and carefully examined. These abalones were compared with red abalones of the same size collected from a nearby mainland area (Isla Vista) where lush stands of large algae persisted after the storm. The results, presented in table 4, illustrate that adult red abalones from Naples Reef were in extremely poor physiological health. For a given shell length, weight of tissues of abalones taken from Naples Reef was only half that of animals captured at Isla Vista. The appearance of adult abalones from Naples Reef was startling; the flesh of the abalones was shrunken, and the animals could easily be picked from the substrate by hand. Isla Vista abalones appeared normal.

It seems possible that the failure of outplanted abalones to survive up to 2 years after planting is attributable to the same cause, that of storm-induced food shortage leading to starvation. Because we cannot separate this source of mortality from that expected of hatchery-reared juvenile abalones that were outplanted, the May 1980 test plant cannot be used to evaluate the long-term success or failure of the outplanting technique.

Table 1

Density of Juvenile Red Abalones (up to 80 mm Shell Length) at the Naples Reef Outplant Study Site*

	Mean No./10 m² (± 95% Confidence Limits)		
	Time from Outplanting		
Site	Immediately Before	17 Weeks After	2 Years After
Experimental site	0.25 (0.80)	3.63 (1.00)	1.00 (2.25)
Control site	0.38 (0.76)	1.13 (1.77)	0.25 (0.46)

Two-way ANOVA: Time from Outplanting X Area

Source of Variation	df	MS	F_s	p Value
Time from outplanting	2	39.542	14.164	≤ 0.001
Site (control vs. experimental)	1	26.583	9.522	≤ 0.01
Time X site interaction	2	14.292	5.119	≤ 0.025

Scheffe's A Posteriori Procedure

	Experimental Site		
Time X experimental site cell means	17 weeks	two years	before

	Control Site		
Time X control site cell means	17 weeks	two years	before

* The control site was not seeded with hatchery abalones while the experimental site received nearly 9,000 juveniles in May 1980. Density of juvenile abalones is given for the time immediately before seeding, 17 weeks after the outplant, and 2 years after planting. The data are the mean density per 10 m² (± 95% confidence interval). Below are the results of a two-way ANOVA (with factors being time in relation to outplanting and site [control versus experimental]). *A posteriori* comparisons of cell means were made using Scheffe's procedure. Means not different are connected with underline.

Table 2

Density of Adult Red Abalones (Greater Than 80 mm Shell Length) at the Naples Reef Study Site*

	Density of Adult Red Abalone	
	Mean No./10 m² (± 95% Confidence Limits)	
Site	Time in Relation to Outplanting	
	Immediately Before	Two Years After
Experimental area	0.54 (0.30)	-0-
Control area	0.47 (0.23)	-0-

* A total of 12 belt transects each 60 x 1 m were examined at each of the control and experimental areas before outplanting and 2 years after outplanting. The data are the mean density per 10 m² (± 95% confidence intervals). No adult red abalones were found on the transects in May 1982.

Table 3

Size Frequency Distributions of Live Red Abalones Found in Random Transects During May 1980, and Dead Shells of Red Abalones Collected by Systematic Searches of the Naples Reef Study Area in May 1982*

Abalone Size Class (mm)	Live Abalones May 1980		Dead Shells May 1982	
Juveniles (≤ 80 mm)	No.	Proportion	No.	Proportion
0 - 20	7	0.18	1	0.08
21 - 40	14	0.35	5	0.42
41 - 60	11	0.28	3	0.25
61 - 80	8	0.20	3	0.25
(Mean size)	(40 mm)		(43 mm)	
Adults ≥ 80 mm)	**No.**	**Proportion**	**No.**	**Proportion**
81 - 100	18	0.16	10	0.11
101 - 120	17	0.15	12	0.13
121 - 140	18	0.16	19	0.21
141 - 160	16	0.14	16	0.18
161 - 180	20	0.17	21	0.23
181 - 200	13	0.11	7	0.08
201 - 220	9	0.08	5	0.05
221 - 240	5	0.04	1	0.01
(Mean size)	(148 mm)		(146 mm)	

* Adult abalones were considered to be animals greater than 80 mm shell length. Also presented are the mean sizes of juvenile and adult abalones in each category.

Table 4

Shell and Tissue Characteristics of Adult Red Abalones*

Abalone Characteristic	Location Where Abalone Collected		Significance Level
	Naples Reef (N = 7)	Isla Vista (N = 6)	
Shell length (mm)	181.3 (10.4)	174.8 (15.7)	not significant
Shell weight (g)	340.9 (81.2)	344.4 (137.5)	not significant
Total tissue weight (g)	273.7 (92.7)	560.9 (178.7)	$p \geqslant 0.01$
Foot tissue weight only (g)	167.1 (62.5)	403.8 (135.2)	$p \geqslant 0.01$

* Data collected from the Naples Reef study area and from a nearby mainland area, Isla Vista. Naples Reef supported abundant large algae up until mid-1980. Isla Vista supported abundant large algae continuously since at least 1978. Presented are the mean values (± 95% confidence limits) and the results of paired student's t-tests.

Cooperating Organizations
Ab Lab
California Abalone Association
California Department of Fish and Game
Santa Barbara County Fish And Game Commission
Santa Barbara County Parks Department

References

BURGE, R., SCHULTZ, S., AND ODEMAR, M. 1975. Draft report on recent abalone research in California with recommendations for management. California Department of Fish and Game Commission report.

GIORGI, A. E. AND DEMARTINI, J. D. 1977. A study on the reproductive biology of the red abalone, *Haliotis rufescens* Swainson, near Mendocino, California. Calif. Fish and Game 63:80-94.

LEIGHTON, D. L. 1974. The influence of temperature on larval and juvenile growth in three species of southern California abalones. Fish Bull. U.S. 72:1137-1145.

MORSE, D. E., TEGNER, M., DUNCAN, H., HOOKER, N., TREVELYAN, G., AND CAMERON, A. 1980. Induction of settling and metamorphosis of planktonic molluscan (*Haliotis*) larvae. III. Signaling by metabolites of intact algae is dependent on contact. In *Chemical Signaling in Vertebrate and Aquatic Animals*, D. Muller-Schwarze and R. M. Silverstein, eds. Plenum Publishing Corp., Plenum, N.Y.

RICHARDS, J. B. 1977. The value of an abalone industry to San Luis Obispo, Santa Barbara, and Ventura Counties. University of California Cooperative Extension publication.

SCHMITT, R., CONNELL, J., DAY, R., SCHROETER, S., AND RICHARDS, J. 1981. University of California, Santa Barbara abalone enhancement program final report. Sea Grant publication.

TUTSCHULTE, T. C. 1975. The comparative ecology of three sympatric abalones. Ph.D. dissertation, University of California, San Diego.

YOUNG, J. S. AND DEMARTINI, J. D. 1970. The reproductive cycle, gonadal histology, and gametogenesis of the red abalone, *Haliotis rufescens* (Swainson). Calif. Fish and Game 56:298-309.

EFFECT OF NEMERTEAN EGG PREDATORS ON THE DUNGENESS CRAB FISHERY

University of California, Santa Barbara
R/F-75
1981-82

Armand Kuris

The landings of the dungeness crab (*Cancer magister*) are cyclical, with a period of 7-10 years in California, Oregon, and Washington. In 1958, after declining from the peak catch of the mid-1950s, the central California fishery collapsed. To study the role of the abundant nemertean worms (*Carcinonemertes errans*) preying on dungeness crab eggs and the brood mortality in general in this fishery, it is necessary to continue to expand the sampling of crab stocks begun by D. E. Wickham (examining worm density and dungeness crab egg loss) through at least one complete cycle of the fishery. Other noncyclical stocks and a related crab fishery are now being monitored for comparison.

Collections of eggs from dungeness crabs fished in central California, northern California, Oregon, and Washington continued to show high levels of infestation of *C. errans* in 1981. We estimate brood losses of 40-60% on crabs from these regions. In contrast, crabs from British Columbia and southeastern Alaska continued to have low-density worm infestations with brood losses estimated from 5-15%. *Cancer anthonyi*, the yellow rock crab that supports a southern California fishery, also exhibited low-density infestations of a *Carcinonemertes* sp. at Santa Barbara. These were associated with a loss of 2-15% of the brood. Additionally, a sample of the shore crab, *Hemigrapsus oregonensis*, an unexploited species, disclosed densities of 1 worm per 50 eggs and complete brood failure in Bodega Harbor.

These samples were collected using improved sampling procedures that increased the reliability and precision of estimating worm density, mortality, and fecundity. The new procedures incorporate the differential mortality of eggs in different regions of the egg clutch and differences in crab embryogenic stages.

The continued high density of worms and the continued egg losses, observed as the dungeness crab catches decline to their cyclical low, extend our observations on this apparent epidemic and support the possible importance of this mortality source on the crab fishery. Noncyclical stocks of *C. magister* as well as *C. anthonyi* do not show epidemic levels. The recent discovery of epidemic levels of *Carcinonemertes* on *H. oregonensis* is surprising. Extensive samples of this crab from 1969-70 indicate that the new outbreak represents an increase in worm densities by a factor of 50. This system now represents the second documented outbreak of nemertean egg predation and suggests that epidemics can occur in unfished crab stocks.

In the course of sampling *C. magister* and *C. anthonyi* populations, we also recorded (for the first time) nemertean egg predators on the spiny lobster (*Panulirus interruptus*) at Santa Barbara; the tanner crab (*Chionoecetes bairdi*) at Seward and Juneau, Alaska; *Telmessus cheiragonus* at Seward, and the king crab (*Paralithodes camtchatkana*) at Juneau. These include the first record of nemertean egg predators from any spiny lobster or anomuran (lithodid) crab.

To provide information on worm growth, predation rates, and reproduction for improved simulation models, we compared growth of worms *in situ*, in the egg mass, with *in vitro* laboratory predation rates using newly designed feeding chambers. Surprisingly, *in vitro* worms grew better and reproduced earlier than worms feeding *in situ*. The *in vitro* worms grew to smaller maximum sizes (3.5 versus 5.0 mm) and ceased reproduction earlier than *in situ* worms, however. These differences suggest the hypothesis that feeding *in situ* may be inhibited by unknown factors early in the embryogenic period. Also, they show that worm growth and maturation are not closely tied to the host embryogenic sequence.

Worm feeding rates *in vitro* reached a maximum of about 0.75 eggs eaten per worm-day on day 10 after host oviposition. During the first 20 days of feeding, about 30% of the eggs are only partially eaten. However, these eggs are unable to complete development and may ultimately succumb to fungal or microbial infections. This predation rate declined to 0.25 eggs per worm-day by day 50. Few eggs were eaten during the last 30 days of host embryogenesis when worm reproduction also ceased.

Egg survival in our feeding chambers was quite high. Fungal infections (in 20% of the eggs) were observed during the first 40 days of the 90-day brooding period. In the last 50 days survivorship was high, few further fungal infections were observed, and many eggs completed development. This observation may have application to crustacean mariculture systems where rearing eggs *in vitro* is often difficult to achieve.

Cross-feeding experiments of *Carcinonemertes* from *C. magister* on eggs of *H. oregonensis* have been successful. Worms have grown and matured on this diet. This suggests that host specificity in the genus *Carcinonemertes* is likely to be ecological rather than physiological in nature.

Laboratory transmission from worm larvae hatched in the laboratory has not been attained. The larvae are strongly photopositive at birth. Attractants used unsuccessfully include whole crabs, whole crab homogenate, crab urine, lysine, GABA, crab water, crab zoea larvae, and adult *Carcinonemertes*. Field transmission studies have been initiated as we have developed techniques to rid crabs of worms without damage to the host.

Studies of juvenile worm transmission have shown that worms transfer from the late premolt exuvium of female crabs to the new cuticle shortly before ecdysis. At this time, worms become active and migrate to the epimeral suture. As the suture widens at the start of ecdysis, over 85% of the worms successfully transfer (see figure 1). No such behavior is observed for juvenile worms on male crabs. We have also observed the transmission of large numbers of juvenile worms from male to female crabs during copulation (see figure 2, worms on male copulatory pleopods). Taken together, these observations indicate that an unexpectedly high proportion of worms are retained by the crab population and transmitted to reproductive female crabs. This tends to maximize the impact of the worms on the crab population. These new observations on worm population dynamics will be included in future simulation models.

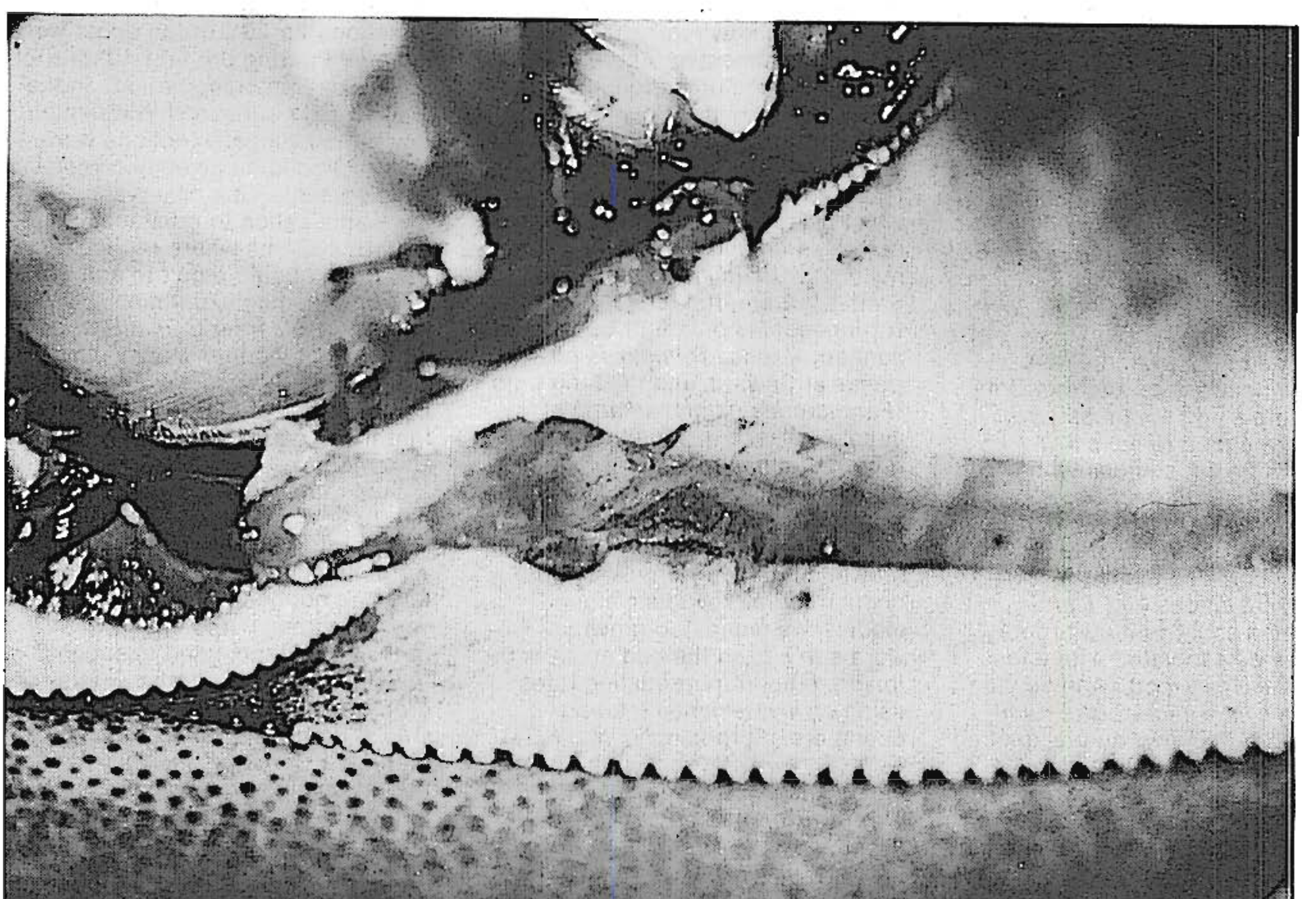


Figure 1. Worms at the suture of a molting female crab.

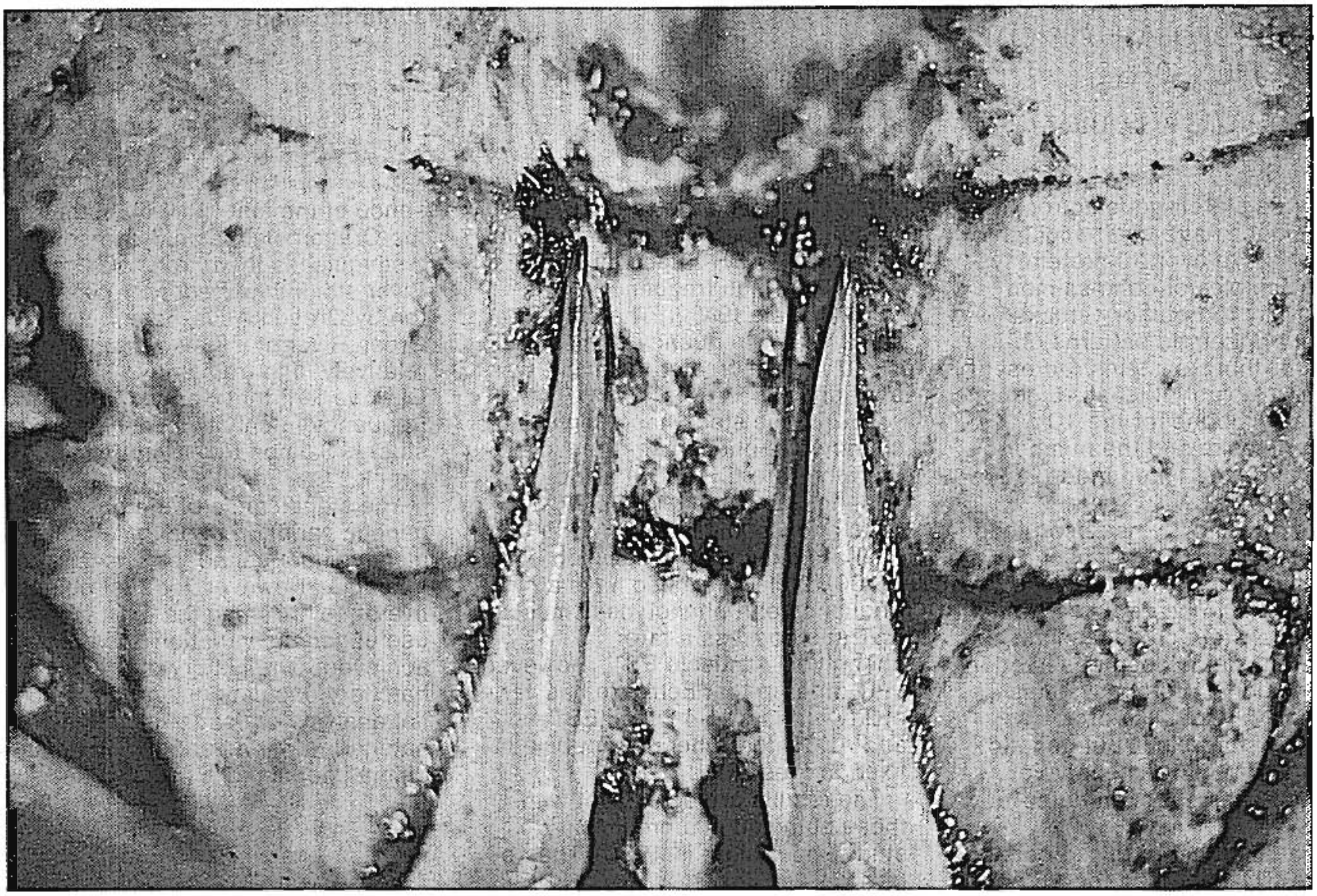


Figure 2. Worms on abdomen of a male crab.

Cooperating Organizations
California Department of Fish and Game
National Marine Fisheries Service, Juneau
Oregon Institute of Marine Biology, University of Oregon
Washington Department of Fisheries, Pacific Biological Station

Publications

WICKHAM, D. E. 1981. *Carcinonemertes*: predator-prey or host-parasite? Paper presented at Symposium on Marine Parasites, Annual Meeting of the Western Society of Naturalists, Santa Barbara, December, 1981.

GENETIC STRUCTURE OF COHO SALMON POPULATIONS ON THE PACIFIC COAST

University of California, Davis
National Marine Fisheries Service, Seattle
R/F-76
1981-82

G. A. E. Gall and F. W. Utter

Standard starch-gel electrophoretic techniques have been applied to the analysis of over 20 protein systems in samples of coho salmon smolts from 10 hatchery stocks. The electrophoretic patterns observed for these systems represent the expression of at least 45 genetic loci. Designations for the 10 hatchery stocks and the number of fish sampled are listed in the table below.

Genetic variability has been found at 16 loci for which the genetic mechanism controlling the observed phenotypes can be deduced from results published on salmonids. Variation has also been observed in three additional protein systems representing variability at a minimum of three loci, but genetic interpretation of the phenotypic differences has not been determined.

Estimates of standardized genetic distance (D'), based on the 16 polymorphic loci only, ranged from 0.001 for the Rogue River and Iron Gate stocks to 0.070 for the Rogue and North Nehalem River stocks. There was a general tendency for geographically neighboring populations to be genetically more similar than populations distant from each other. However, there were some important exceptions to this generalization. The estimated genetic distances between the Rock Creek and Alsea, the Rock Creek and Eel Lake, and the Coquille and Rogue stocks were all about 0.022 while the distance between Trask and the Coquille and Rogue stocks averaged 0.061. Three stocks, Alsea, Eel Lake, and Iron Gate had pairwise distances of about 0.048.

A few specific genetic differences were observed between stocks that will be particularly useful in a mixed fishery analysis. Fish Hawk possesses the variant AAT-4(120) allele at a frequency of 11%, which was not found in any of the other hatchery stocks. The Salmon River stock is characterized by a high frequency of a slow EST variant (23%), a high frequency of the ACON(90) allele (11%), and the rare GL-1(120) allele (3%). Iron Gate was found to have a rare LDH-4 fast variant (1%) and a very high frequency of the TFN(A) allele (84%). The only other stock with a frequency of the TFN(A) allele greater than 55% was the Rogue.

The Rogue stock has a high frequency of a phenotype-1 muscle EST, the rare IDH-4(80) allele (2%), and the GL-2(B) allele (86%). Eel Lake and Coquille are similar in that both are fixed for the common PGI-2(100) allele; they also have a high frequency of a phenotype-3 muscle EST and possess a rare phenotype-4 muscle EST. However, they differ in that Eel Lake has variability at the IDH-4, blood EST-2, and ACON loci whereas Coquille is fixed at these loci.

The results are consistent with those obtained in a preliminary study undertaken in 1980. The absence of the fast LDH-4 variant from the Oregon stocks analyzed so far distinguishes them from the Green River stock imported from Washington by Oregon Aqua-Foods. The Green River stock also possessed a relatively high frequency (6%) of the GL-1 variant that was found at low frequency in only two Oregon stocks, Salmon River and Rock Creek.

The significance of the observed genetic variation to coho salmon management cannot be assessed at this time. However, the first objective of establishing the existence of useful genetic variation has been achieved. The history of the hatchery populations and the potential analysis of fish transfers among hatcheries will be addressed as additional populations are sampled.

Table 1

Coho Salmon — Sampling of Hatchery Smolts

Stock*	Sample Size	Stock Designation and Source
9	80	Fish Hawk (N. Nehalem River)
5	103	North Nehalem River
2	87	Trask River
1	86	Salmon River
8	92	Alsea River
4	74	Rock Creek (Umqua River)
7	120	Eel Lake (Tenmile Lakes)
6	74	Coquille River
3	70	Rogue River
10	93	Iron Gate (Klamath River)

*Stocks listed in order of geographic location from north to south.

Cooperating Organizations
California Department of Fish and Game
Oregon Department of Fish and Wildlife

ARTIFICIAL IMPRINTING OF CHINOOK AND COHO SALMON IN A MULTISPECIES HATCHERY

Humboldt State University
R/F-77
1981-82

Thomas J. Hassler

The Mad River hatchery is one of six salmon and steelhead hatcheries operated by the California Department of Fish and Game. It is the only hatchery designated for the maintenance and enhancement of salmonid runs in California. The hatchery, located 19 km from the ocean on the Mad River (at Blue Lake, California), produces chinook salmon, coho salmon, and steelhead trout. It is equipped to raise 5 million fingerling chinook salmon to an age of 90 days, 200,000 coho salmon and 700,000 steelhead trout to the yearling stage.

To produce the chinook fingerlings, 7 million eggs from about 1,500 mature females must be taken. An egg take of 280,000 from 140 mature females is needed for coho salmon. The mean number of adult female chinook and coho salmon spawned at Mad River hatchery from 1972 through 1981 has been only 61 and 106 respectively — far below the numbers needed for full production. The low return of mature salmon may be due, in part, to poor homing of fish to the hatchery fish ladder.

The hatchery raceways are supplied by recirculated well water, whereas the fish ladder is supplied with single-pass river water. Of the water in the ladder, about 15% is from the hatchery and 85% from the river water. Thus the hatchery water, upon which the juvenile salmon are imprinted, may not be fully used as a homing attractant and returning salmon may fail to locate or recognize the fish ladder, and continue migrating upstream.

Chinook and coho salmon, hatched and raised in Mad River hatchery, were marked and imprinted with morpholine. The fish were divided into two groups, treated and control, and fin-clipped or marked with wire tags. The treated fish were exposed to about 5×10^{-5} mg/liter of morpholine in the hatchery raceway for at least 17 days before being released into the Mad River. The chemical was metered into the raceway from a stock solution by a preset piston pump. The morpholine stock solution was refilled every 48 hours. The control fish were placed upstream in the same raceway and were not exposed to the morpholine. Thus, both groups were reared under nearly the same environmental conditions.

Four experimental groups of fish were used in the project (table 1). All the 1977 brood year (BY) chinook salmon and the 1977 and 1978 BY coho salmon were fin clipped and used in the experiment. Only 39% of chinook salmon of the 1979 BY were tagged with coded wire tags because the tagging machines were available for only a short time.

The Na^+, K^+-activated adenosinetriphosphatase (Na^+, K^+-ATPase) activity was monitored to determine the optimal release time for coho salmon and the 1979 BY chinook salmon. The 1977 BY chinook salmon, which had severe disease problems at the hatchery, were released when the fish silvered and began to display smolting behavior. The 1977 and 1978 BY coho, and the 1977 BY chinook salmon were released directly from the hatchery into the Mad River; the 1979 BY chinook salmon were trucked 9 km downstream and released.

When the mature chinook and coho salmon began to return to the hatchery in September, sufficient morpholine was added to the water passing over the hatchery fish ladder to maintain the compound near the concentration at which the fish had been imprinted. Morpholine was added to the ladder water from mid-September through early January from a stock solution delivered by a preset piston pump. Hatchery personnel sorted returned fish weekly from September through October and twice a week from October through December. The numbers of imprinted and control fish that had returned to the hatchery were counted each time the fish were sorted. Returns of treated and control chinook and coho salmon were compared to test null hypotheses that there were no significant differences in returns by brood year and species between imprinted and control groups. G-tests were used for all comparisons.

A total of 39 morpholine-imprinted and 26 control chinook salmon and 157 imprinted and 43 control coho salmon returned to Mad River hatchery during the 1979, 1980, and 1981 spawning runs (table 2). In both experiments with coho salmon (experiments 2 and 3, table 2) the percentage of morpholine-imprinted fish that returned was significantly higher than that of control fish ($p < 0.005$). There was no significant difference between returns of imprinted and control chinook salmon.

Only 5 experimental adult fish returned to the hatchery during 1981, but 33 chinook grilse of 1979 BY returned (table 2). There was no significant difference between the return of imprinted and control chinook grilse.

In two separate experiments over a period of three spawning seasons there was a significantly greater return to Mad River hatchery of morpholine-imprinted coho salmon than of control fish. There was no significant difference in the returns of imprinted and control chinook salmon, however the return of 1979 BY fish were all grilse and more fish returned in 1982 and more are expected to return in 1983.

The return of 1977 BY fish was less than expected: only 32 fish returned to the hatchery during the three spawning seasons. This may have been due to their severe disease problems prior to release, the late release date, and the low river flows at release and during the 1979 and 1980 spawning seasons. This group (experiment 1) had "Ich" (*Ichthyophthirius multifilis*) and were treated twice with acetic acid, once several months before the fish were marked and imprinted and again after they were marked. The first outbreak occurred while they were in a raceway where water was being treated with ultraviolet light (UV). The chinook salmon were at the end of the raceway and probably contracted the disease from fish placed higher up in the same raceway for treatment. Before the fish were marked they were moved to a raceway without UV. After the fish were marked, abnormally high water temperatures occurred and the disease reoccurred causing mass mortalities. About 15% of the imprinted fish died in the hatchery raceway from late September to early November. Only 9% of the control fish died during the same period, under the same conditions. The morpholine-imprinted fish were probably in poorer health than the control fish at the time of release. This difference may have contributed to the low return of treated fish. Many fish of both groups were probably too weak to undergo the physiological stress that is associated with migration and entry into seawater. This condition alone could account for the poor returns of fish of this brood year. Also, the situation was further complicated by an unusually late fall freshet. The first rain did not occur until December, after the fish had been held for an extended period.

Several factors extrinsic to the design of the experiment made interpretation of the results difficult. During the fall of 1979 and 1980 the rainfall was irregular and sparse in the Mad River Basin. After some small rainstorms early in the spawning seasons of both years, fish moved into the river. Immediately thereafter the river flows decreased. The reduced flows caused the salmon to stop moving and to remain in deep pools. Many of these vulnerable fish were caught, legally and illegally, during this time. Consequently, many fish did not survive to reach the fish ladder site. The hatchery also ran an electric weir continuously during the salmon spawning season with the hope of increasing hatchery returns. The weir was immediately above the entrance to the fish ladder. During the fall of 1979 the river was usually high enough for some salmon to swim around the weir. During the fall of 1980 the first significant freshet did not occur until December 2 and the weir completely spanned the river and effectively stopped most migrating fish. The fish remained in the pools below the weir and many salmon that would normally have entered the hatchery were caught and snagged by fishermen. This could have further reduced hatchery returns.

Because it is possible to imprint coho salmon to morpholine, it should be possible to direct the final stages of the spawning migration. There are several management implications of artificial imprinting. Fish could be directed to return to a particular hatchery, to an area with favorable spawning conditions, or led away from hazardous conditions (landslides, waterfalls, sluice-outs, etc.). Some previously damaged tributaries could be restocked cheaply by imprinting salmon at a hatchery and then later decoying them to these streams.

In summary, it appears that morpholine can be used as an imprinting compound in an anadromous fish hatchery and that the freshwater migrations of some species of salmonids can be manipulated. Coho salmon in two separate experiments were imprinted to morpholine and returned to the hatchery fish ladder in significantly greater numbers than nonimprinted fish. However, there was no difference in returns of chinook salmon. The poor return of 1977 BY chinook salmon was probably due to disease, late release date, low river flows both at release and during the fall when the fish were trying to return to the hatchery. In addition, it appears that a June release for chinook salmon favors survival. The 1979 BY had a good grilse return to the hatchery in 1981, and many fish were caught in the ocean fishery, some as far away as Alaska. Because of the grilse return in 1981 and the appearance of the fish in the ocean fishery we expect a good return to the hatchery in 1982 and 1983 of 1979 BY chinook.

Table 1

Description and Treatment of Salmon Used in Imprinting Experiments with Morpholine, Mad River Hatchery, California, 1978-1980

Experiment	Species	Brood Year	Days Imprinted	Number Released and Mark[a] Imprinted	Control	Date Released
1	Chinook	1977	40	40,180 LV	41,800 LP	Dec. 1978
2	Coho	1977	41	50,800 LV	38,418 LP	Apr. 1979
3	Coho	1978	42	11,170 LV	8,367 RV	Apr. 1980
4	Chinook	1979	17	18,164 CWT	18,218 CWT	June 1980

[a]LV = left ventral, LP = left pectoral, RV = right ventral, CWT = coded wire tag and adipose clip.

Table 2

Return of Experimental Fish to Mad River Hatchery, California 1979-1981

Year Returned	Experiment	Species	Brood Year	Number Released[a]	Number Returned Grilse[b]	Adult	G-test
1979	1	Chinook	1977	40,180 I	9	--	P ⩾ 0.650
				41,800 C	8	--	
	2	Coho	1977	50,800 I	25	--	P ⩾ 0.300
				38,418 C	13	--	
1980	1	Chinook	1977	40,180 I	--	9	P ⩾ 0.200
				41,800 C	--	4	
	2	Coho	1977	50,800 I	--	54	P ⩾ 0.005
				38,418 C	--	8	
	3	Coho	1978	11,170 I	76	--	R ⩾ 0.005
				8,367 C	21	--	
1981	1	Chinook	1977	40,180 I	--	1	--
				41,800 C	--	1	
	2	Coho	1977	50,800 I	--	1	--
				38,418 C	--	1	
	3	Coho	1978	11,170 I	--	1	--
				8,367 C	--	0	
	4	Chinook	1979	18,164 I	20	--	R ⩾ 0.200
				18,218 C	13	--	
Total	1	Chinook	1977	40,180 I	19		P ⩾ 0.200
				41,800 C	13		
	2	Coho	1977	50,800 I	80		P ⩾ 0.005
				38,418 C	22		
	3	Coho	1978	11,170 I	77		P ⩾ 0.005
				8,367 C	21		
	4	Chinook	1979	18,164 I	20		P ⩾ 0.200
				18,218 C	13		

[a]I = imprinted, C = control
[b]Precocious spawners

Cooperating Organizations
Alaska Division of Fish and Wildlife
California Department of Fish and Game
Humboldt State University
National Marine Fisheries Service
Oregon Division of Fish and Wildlife
U.S. Fish and Wildlife Service
Washington Division of Fish and Wildlife

Publications

HASSLER, T. J. 1982. Artificial imprinting of salmon in an anadromous fish hatchery. Paper presented at Western Division American Fisheries Society, July 1982, Las Vegas, Nevada.

HASSLER, T. J. AND KUCAS, S. T. In press. 1982. Artificial imprinting of salmon in an anadromous fish hatchery. In *62nd Proceedings, Western Association of Fish amd Wildlife Agencies*. Las Vegas, Nevada.

KUCAS, S. T. AND HASSLER, T. J. 1982. Morpholine imprinting of chinook and coho salmon in an anadromous fish hatchery. Paper presented at Cal-Neva Chapter American Fisheries Society Annual Meeting, January 1982, Reno, Nevada.

KUCAS, S. T., JR. 1981. Morpholine imprinting of chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) in an anadromous fish hatchery. M.S. thesis, Humboldt State University, Arcata, California.

ENDOCRINE CONTROL OF SALMONID DEVELOPMENT AND SEAWATER ADAPTATION

University of California, Berkeley
R/F-78
1981-82

Howard A. Bern, Charles S. Nicoll, and Richard S. Nishioka

When young salmon, especially coho (*Oncorhyncus kisutch*), that have not or are not ready to undergo smoltification are transferred to seawater in an aquaculture or fish husbandry operation, there is high mortality and/or drastic stunting (parr-reversal). A similar condition may prevail when improperly smoltified fish are released in large numbers from hatcheries. A thorough understanding of the endocrinological basis of stunting may provide a method of reducing economic loss. Our studies are particularly concerned with attempts to reduce or eliminate stunting or parr-reversal, which is known to occur within the confines of seapens, to minimize potential losses at sea, and to improve success in transfer and returns with the use of hormones.

In the second year of a continuing study, more than 350,000 binary-coded wire nose-tagged coho salmon have been released from the Trinity and Iron Gate Hatcheries in northern California. Based on our lunar hypothesis of smoltification-associated thyroid hormone surge, release dates from each hatchery were determined in consultation with our laboratory. Five releases of about 50,000 fish from the Trinity Hatchery and four releases of about 25,000 fish from the Iron Gate Hatchery were made in the spring of 1982. The five dates chosen this year for Trinity Hatchery were February 16, March 4 and 25, and April 8 and 23 (with the March 4 date omitted for the Iron Gate Hatchery). The production of young salmon with the ability to migrate successfully to the ocean and to thrive and grow there is the goal of this project.

Coho salmon normally spend 2 to 3 years at sea prior to returning to fresh water to spawn. However, a small percentage of fish return to the hatchery after spending less than a year at sea. These small, precociously mature early returnees, known as grilse or jacks, do not contribute to the fishery but have been used as an indicator of migratory success and seawater survival of the major group. In 1981, 999 grilse returned in October and November to Trinity Hatchery from five spring release dates in 1981; of these, 320 (32%) were from the group released on April 16, the date of the new moon coincident with the thyroxin peak in 1981. Only 54 grilse returned to the Iron Gate Hatchery, and no pattern of better oceanic survival could be discerned. Mature adult returnees late this fall (1982), in addition to ocean harvest of tagged fish, should provide a better basis for selection of optimal fish release dates and lead to improved hatchery practices.

Our identification of lunar phasing as an element in the timing of the smoltification-associated thyroxin surge led us to question what element of the lunar cycle was used as the timing cue. To this end, an investigation employing three treatments was established at the Pacific Biological Station in Nanaimo, British Columbia. Groups of coho salmon were maintained in a natural moonlight cycle, without the light component of the lunar cycle, and in an artificial moonlight cycle 180 degrees out of phase with the natural cycle. Moonlight does not appear to be a factor timing the occurrence of the smoltification-associated thyroxin surge.

An investigation of the change in circulating thyroxin level that occurs during smoltification and upon entry into the marine environment was conducted. The experiment was designed to provide answers to these questions: 1) What is the time course (profile) in the plasma thyroxin response to a single injection of 0.1 IU bovine thyrotropin (TSH)? 2) How does this profile compare between salmon in the presmolt parr stage (March 19, 1982) and in the smolt stage (May 24, 1982)? 3) How does this response change when the salmon are transferred to seawater following TSH injection? 4) Does the response to seawater entry following TSH injection differ between presmolt- and smolt-stage salmon? The results suggest that thyroid gland activity, as measured by plasma thyroxin concentration, is stimulated by TSH in presmolt- and smolt-stage salmon in both fresh water and seawater.

Thyroid function in juvenile coho salmon was evaluated at different stages of development and environmental salinity. In this particular study, performed on presmolt-stage (March) and smolt-stage (May) coho salmon, radiolabeled thyroxin was injected into the heart, and small volumes of blood were serially sampled from the caudal vasculature. Three samples were obtained within 0.5 hour from one group of fish, and another group of fish was sampled at 24 hours and 48 hours. All fish were sampled at 3 minutes to confirm intracardiac delivery of the labeled hormone. Preliminary analysis indicates that thyroxin secretion and plasma clearance rates are generally similar in presmolt-stage and smolt-stage salmon regardless of freshwater or marine habitat. The results suggest that the increase in thyroid activity which occurs during smoltification may be due to a higher set-point for the negative feedback of thyroxin at the hypothalamo-pituitary level.

In order to determine the long-term effects of seawater transfer on the growth of coho salmon during and after smoltification and to test the hypothesis that stunted coho salmon have low thyroxin levels, in August 1981 (Group I, 1200 fish), February 1982 (Group II, 360 fish) and March 1982 (Group III, 360 fish) coho salmon from the Iron Gate Hatchery in northern California were transported to the Bodega Marine Laboratory and were transferred to three large indoor tanks (freshwater, seawater, and a seawater acclimation tank). Blood samples, observations of smolt characteristics, and length and weight measurements were taken on an irregular basis from mid-August to November 1981 (Group I), and from mid-February and mid-March 1982 to September 1982 (Groups II and III). Plasma thyroxin levels have not yet been analyzed. By late October Group I seawater (SW) fish weighed more than freshwater (FW) fish and SW-acclimated fish. Fish from Groups II and III directly transferred to SW weighed considerably less than their FW counterparts after 4 or 5 months in SW (July 1982). Seawater-acclimated fish were growing as well as FW fish at the time of the latest sampling (July 1982) in Groups II and III. Neither Group II nor III underwent dramatic growth in FW or SW from February to July. These studies should help to assess proper times of transfer to SW for seapen culture with the aim of reducing high mortality and stunting of growth.

In order to ascertain whether the time of smoltification can be advanced in steelhead trout by treatment with thyroid hormones and whether thyroid hormones will improve home-stream imprinting, differentially marked (freeze-branded) steelhead trout at the Coleman National Hatchery were kept on an experimental feeding program from January 25 to February 23, 1982, with 45,000 triiodothyronine (T_3)-fed (12 ppm) and 45,000 control fish as the two groups. Observations of smolt characteristics and collections for blood samples and length and weight measurements were scheduled for full, new, and quarter moon days from mid-January to late May 1982. Data analyzed to this point show that 1) there is a substantial negative feedback effect of T_3 in lowering thyroxin levels prior to the thyroxin surge; 2) both control and T_3-fed groups underwent a sharp increase in thyroxin at the last quarter of the moon in February, with no negative feedback effects of T_3 on thyroxin levels; 3) after completion of T_3 feeding, there is no difference in thyroxin levels between T_3-fed and control groups; and 4) there is no significant difference in growth, as reflected by weight, between T_3-fed and control groups in fresh water or seawater. However, some indication of behavioral changes was noted in T_3-fed fish. Future studies will consider behavioral changes, and T_3 feeding will begin earlier.

In order to determine if new moon-associated peaks in thyroxin (T_4) levels occur during the fall in king salmon in the Sacramento system as well, blood samples were taken at the Merced, Mokelumne, and Nimbus Hatcheries in the fall of 1981. Merced Hatchery fish showed a distinct (T_4) peak on the new moon in November, with a possible secondary peak in December. Mokelumne Hatchery fish showed evidence of new moon peaks in late September and late October, while Nimbus Hatchery fish did not show any peaks.

We have developed a rapid, sensitive, and specific bioassay for salmon prolactin (PRL) using the hypophysectomized killifish, *Fundulus heteroclitus*. These animals respond to PRLs of both mammalian and teleost origin but are much more sensitive to the latter. The effective dose of a highly purified chinook salmon (*Oncorhynchus tschawytscha*) PRL (250 pg/gm) was two orders of magnitude lower than that for ovine PRL (NIH-P-S10). Coho pituitaries have been incubated to provide secreted PRL and growth hormone for development of radioimmunoassay and radioreceptor assays.

Cooperating Organizations
Pacific Biological Station, Nanaimo, B.C.
Department of Medicine and Computer Science, UCLA
California Department of Fish and Game
Laboratory of Fish Physiology, Rennes, France

Publications

BERN, H. A. 1982. Epilogue to Symposium on Salmon Smoltification. Aquaculture 28(1-2):269-270.

BERN, H. A. AND MAHNKEN, C. V. W., EDS. 1982. Salmonid Smoltification. Aquaculture 28 (1-2):v-x, 1-270. Elsevier Scientific Publishing Company, Amsterdam.

COLLIE, N. L. AND BERN, H. A. In press. Changes in intestinal fluid transport associated with smoltification and seawater adaptation in coho salmon (Oncorhynchus kisutch). Journal of Fish Biology.

GRAU, E. G. In press. Is the lunar cycle a factor timing the onset of salmonid migration? In *Proc., Symposium on Salmon and Trout Migratory Behavior.* College of Fisheries, University of Washington, Seattle, June 1981.

GRAU, E. G. In press. Is the lunar cycle an important factor timing the onset of salmonid migrations? ORI Symposium on Fish Migration and Reproduction, Tokyo, Japan, December 1981.

GRAU, E. G., BERN, H. A., AND NISHIOKA, R. S. 1982. Changes in thyroid function during the development of salmon. Sixty-fourth Annual Meeting of the Endocrine Society, June 1982, San Francisco. (Abstract).

GRAU, E. G., NISHIOKA, R. S., SPECKER, J. L., AND BERN, H. A. In press. 1981. Endocrine involvement in the smoltification of salmon. XI International Symposium on Comparative Endocrinology, Hong Kong, December 1981.

GRAU, E. G., SPECKER, J. L., NISHIOKA, R. S., AND BERN, H. A. 1982. Factors determining the occurrence of the surge in thyroid activity in salmon during smoltification. Aquaculture 28(1-2):49-58.

LORETZ, C. A., COLLIE, N. L., RICHMAN, N. H., III, AND BERN, H. A. 1982. Osmoregulatory changes accompanying smoltification in coho salmon. Aquaculture 28(1-2):67-74.

NAGAHAMA, Y., ADACHI, S., TASHIRO, F., AND GRAU, E. G. 1982. Some endocrine factors affecting the development of seawater tolerance during the parr-smolt transformation of the amago salmon *Oncorhynchus rhodurus.* Aquaculture 28(1-2):81-90.

NISHIOKA, R. S., BERN, H. A., LAI, K. V., NAGAHAMA, Y., AND GRAU, E. G. 1982. Changes in the endocrine organs of coho salmon during normal and abnormal smoltification — an electron-microscope study. Aquaculture 28(1-2):21-38.

SPECKER, J. L. 1982. Interrenal function and smoltification. Aquaculture 28(1-2):59-66.

BIOCHEMISTRY OF FAT DEPLETION DURING SALMONID SMOLT TRANSFORMATION

Humboldt State University
R/F-79
1981-82

Theodore Kerstetter and William V. Allen

This 1-year project was intended to define the changes in tissue and blood lipid composition which attend smolting in steelhead trout and to identify the enzymatic agents of said changes. The work was an attempt to explain the often-noted fact that smolting salmonids utilize much of their tissue lipid stores.

A population of steelhead trout from Prairie Creek Hatchery, Humboldt County, was sampled biweekly from January through April, 1982. Smolt status was assessed by gill ATPase activity; total lipid and lipid class compositions of serum and tissues (mesenteric fat, liver, dark muscle, and light muscle) were determined.

A decrease in the total lipids of serum, dark muscle, light muscle, and liver occurred as smolting progressed. Most of the decrease in total lipid could be attributed to a diminution in triglycerides. Smaller declines were noted for such other lipid classes as wax esters, cholesterol, cholesterol esters, and free fatty acids. The pattern of depletion of triglycerides from dark muscle, light muscle, and liver suggested that all of these tissues as well as mesenteric fat serve as fuel stores which are drawn down during smolting.

An enzyme that is key to triglyceride utilization, hormone-sensitive lipase, was purified from mesenteric fat by affinity chromatography. Preliminary results indicated that the activity of this enzyme in dark muscle (a tissue rich in triglycerides) increased during smolting. This finding may mean that fat depletion in smolting salmonids is controlled by endocrine mechanisms similar to those that have been demonstrated in mammals.

Some incidental findings of the project included: wax esters, a lipid class rarely found in the serum of vertebrates, occurred in both serum and liver but not other tissues of steelhead; chylomicron-like lipoproteins appear in the serum of steelhead shortly after eating fat-rich food — a result that is at odds with presently accepted accounts of lipid absorption and transport by the gut of fish.

Sea Grant trainee Mark Sheridan is continuing work on hormone-sensitive lipases as part of his doctoral research at the University of California, Berkeley.

Cooperating Organizations
Prairie Creek Fish Hatchery (operated by Humboldt County)

Publications

Allen, W. V. and Sheridan, M. A. In prep. A review of lipid transport in the blood of fish. (To be submitted to J. Fish Biol.).

Sheridan, M. A. 1982. Seasonal variations in the lipid composition of the steelhead trout, *Salmo gairdneri* Richardson, associated with the parr-smolt transformation. M.A. Thesis, Humboldt State University.

Sheridan, M. A. and Allen, W. V. In press. Wax esters in the serum and liver of the juvenile steelhead trout (*Salmo gairdneri*, Richardson). Comp. Biochem. Physiol.

Sheridan, M. A. and Allen, W. V. In prep. Changes in the fatty acid composition of the steelhead trout, *Salmo gairdneri* Richardson, associated with the parr-smolt transformation. (To be submitted to Comp. Biochem. Physiol.).

Sheridan, M. A. and Allen, W. V. In prep. The presence of triacylglycerol hydrolase activity in the dark muscle of steelhead trout (*Salmo Gairdneri*) and its relationship to lipid transport. (To be submitted to Comp. Biochem. Physiol.).

Sheridan, M. A., Allen, W. V., and Kerstetter, T. H. In press. Seasonal variations in the lipid composition of the steelhead trout, *Salmo gairdneri* Richardson, associated with parr-smolt transformation. J. Fish Biol.

NEW MARINE PRODUCTS

MARINE CHEMISTRY AND PHARMACOLOGY PROGRAM: PHARMACOLOGICAL SCREENING AND EVALUATION

University of California, Santa Barbara
R/MP-21
1980-82

Robert S. Jacobs

Our effort to test and develop new pharmacological compounds has yielded biologically interesting compounds in three areas: inhibition of cell division, inhibition of the inflammatory process, and effects on skeletal muscle and neuromuscular activity. Based on this experience, in 1981-1982 we added new assays to screening procedures: the mouse ear edema assay for inhibition of topical inflammation, the electrically stimulated frog ventricle strip for effects on heart muscle, and the sea urchin sperm motility assay for spermicidal activity. These assays provide consistent results in precise areas and promise to detect a significant number of marine compounds with potential for clinical use. Their addition has allowed transfer of less productive procedures to the status of "follow-up" testing.

Three compounds continue to be of overriding interest due to their apparently unique mechanisms of action. These are lophotoxin, manoalide, and stypoldione.

Lophotoxin

The toxin (lophotoxin) is a rare chemical structure obtained by chloroform extraction from three Mexican *Lophogorgia* species (*L. alba*, *L. cuspidata*, and *L. rigida*), and the California gorgonian, *L. chilensis*. Studies of the crude extracts were made by William Fenical and myself, along with a group of graduate students and staff from Scripps during May and June of 1978 on board the *Alpha Helix*. During that expedition we found the extracts to be toxic to fish, and thin-layer chromatography suggested the presence of an as yet unidentified chemical entity. Subsequent to this, Fenical isolated and purified the lophotoxin and passed the compound on to us for further investigation.

Paul Culver (graduate student) undertook an investigation of lophotoxin, beginning with parenteral injection in mice. We observed acute toxicity that was qualitatively similar to administration of curare, although the onset of toxicity was considerably delayed. Careful inspection of the animals during the onset of toxicity indicated that death was due to respiratory paralysis. Thus, to determine if the paralysis occured by an action on the central nervous system or the peripheral nervous system, we initiated a study in the isolated rat diaphragm *in vitro*. We sought to discover 1) if lophotoxin paralyzes *in vitro* preparations, 2) what the pharmacokinetics of the response are compared to known drugs, 3) if lophotoxin is reversible, and 4) what lophotoxin's site of action is — does it act presynaptically on the nerve or postsynaptically (e.g., on the end plate or on one of the postjunctional steps involved in excitation-coupling of muscle contraction).

In the rat diaphragm our findings are as follows. Lophotoxin is a potent neuromuscular toxin, it is irreversible, and the pharmacokinetics of its action are identical to the snake venom α-bungarotoxin. It is quite different from d-tubocurare or any of the known reversible neuromuscular blocking agents, both pharmacologically and chemically. That is, lophotoxin is devoid of the cationic groups common to reversible curare-like agents and has no chemical relationship to any of the known irreversible toxins — these substances are largely polypeptides composed of 32-64 amino acid sequences. Like the curare-like agents, the binding of α-bungarotoxin to receptors requires nitrogen-containing functional groups. Lophotoxin is a hydrophobic molecule that we suspected may bind to sites other than the classical sites.

In studies of diaphragms in which we applied direct stimulation to the muscle, we were unable to produce a paralysis with lophotoxin — paralysis was only produced in nerve-stimulated preparations. Thus, the site of action of lophotoxin was believed to be primarily on the nerve or synapse.

The pharmacokinetics of the action of lophotoxin is also a very interesting question. The latency of the response — the time before paralysis ensues — is delayed in comparison to other drugs. With decreasing concentrations of lophotoxin, there is a lengthening of the latency interval and a reduction in the rate at which the neuromuscular blockade develops. Concentrations as low as 8×10^{-6} M require over 3 hours for paralysis to develop. It is always irreversible and a given concentration does not require constant exposure to the preparation in order to produce paralysis. That is, a given dose can be added to the bath, subsequently washed out and full paralysis still ensues. We do not believe this latency of response is due to diffusion barriers because we have observed the same latency during the blockade of end plate potentials recorded intracellularly in surface cells of frog sartorius muscles.

The next question we have attempted to answer is whether lophotoxin acts at the same site at the muscle end plate in rat diaphragms as radiolabeled α-bungarotoxin. Briefly, we have demonstrated that curare competes effectively with α-bungarotoxin for its binding site. Lophotoxin, on the other hand, is a weak competitor for the α-bungarotoxin site, suggesting to us that our original suspicions were correct — lophotoxin may act by blocking at a site other than the classical nicotinic receptor or, at least, the process or mechanism is different from known drugs.

Continuing study of this unusual molecule has produced further evidence that lophotoxin acts postsynaptically. Microelectrode studies have ruled out effects on transmitter release, rate of nerve conduction, and membrane resistance and capacitance.

Manoalide

We have discovered that manoalide, an antibiotic sesterterpene from the marine sponge

Luffariella variabilis, is a potent topically active anti-inflammatory and analgesic agent. This substance, originally isolated by de Silva and Scheuer, was also isolated by Faulkner in substantive quantities and sent to us for study as part of our overall collaborative marine chemistry and pharmacology program.

We subjected this compound to extensive study after finding it active against phenylquinone-induced pain. The onset of action of manoalide was delayed in comparison to other standard analgesics active against phenylquinone; the peak effect was detected about 2 hours after administration (subcutaneous).

On the basis of these results we undertook studies to determine if manoalide had a profile of activity similar to aspirin and indomethacin, or similar to morphine. (If it were similar to the former compounds, manoalide should have activity as an anti-inflammatory agent; if similar to morphine it should be active in specialized assays sensitive to morphine and the endorphins.)

In order to determine if this compound had activity similar to morphine, we explored manoalide's action on the electrically driven ileum and assessed its action as an analgesic using the Haffner technique. In the ileum, manoalide neither blocked electrically induced contractions, an effect common to both morphine and the endorphins, nor did it antagonize the morphine block as would be expected if it had properties common to nalorphine. Similarly, high doses of manoalide did not significantly affect pain induced by the Haffner technique, whereas morphine was uniformly *active*.

Because of these results, we decided to determine if manoalide had anti-inflammatory activity similar to indomethacin. This is based on the observation that indomethacin is also active against phenylquinone writhing and is an effective analgesic. In this case we utilized the PMA-induced inflammation in the mouse ear. We had several reasons for doing this. First, the hydrophobic nature of manoalide, along with its weak analgesic action, suggested that there could be significant nonspecific binding of the molecule that would limit this drug's action (i.e., high doses are required to demonstrate the analgesic effect when it is administered subcutaneously). Second, other test models required chronic administration of manoalide and they did not lend themselves to basic investigations as easily as the mouse ear. In the latter case, the agonist and antagonist are applied topically to the ear and the response measured over a 3-hour period. In manoalide-treated ears there is a marked reduction of inflammation due to PMA induction when doses as low as 20 μg were applied. Histological examination of the ear showed that manoalide gave results quantitatively similar to both hydrocortisone and indomethacin. Manoalide, when topically applied, is more potent than indomethacin and less potent than the steroidal anti-inflammatory agent, hydrocortisone.

The next question posed was whether manoalide had a mechanism of action similar to hydrocortisone or to indomethacin. In this case the working hypothesis we employed was from recent reports in the literature dealing with the mechanism of action of PMA-induced inflammation.

Simply stated, PMA causes the release of arachidonic acid (ARA) from lysosomes. The released ARA is the substrate for the synthesis of prostaglandin (PGE) which is believed to contribute to pain and inflammation. Hydrocortisone is believed to exert its anti-inflammatory effect in part to "stabilizing lysosomes" and thereby preventing release of ARA. Indomethacin, on the other hand, acts to inhibit prostaglandin synthetase and by this mechanism prevents formation of PGE. Using this model, we hypothesized that direct administration of ARA should produce an inflammatory response qualitatively similar to PMA inflammation if it is sufficiently absorbed when applied topically. We found this to be the case. When ARA is applied to the mouse ear topically, edema and inflammation develop within 1 hour of application. PMA administration, on the other hand, takes 3 hours for the inflammation to develop.

ARA inflammation is effectively blocked by indomethacin over the same dosage range as PMA inflammation. Neither manoalide nor hydrocortisone affected the ARA inflammation at any of the doses employed.

For comparison of manoalide with steroidal anti-inflammatory agents, chronic studies were undertaken. Injection of manoalide (50 mg/kg) or hydrocortisone (25 mg/kg) daily for 7 days showed that manoalide's spectrum of activity is not the same as that of hydrocortisone (i.e., no thymus involution or effect on adrenals) but that manoalide is acutely immunosuppressive.

Our current focus is on the ability of manoalide to (1) inactivate phospholipase A_2 *in vitro* and (2) inactivate α-bungarotoxin's neurotoxic effects *in vitro*.

Stypoldione

When isolated from the brown alga, *S. zonal*, stypoldione was shown to be 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 following observations were made. 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 when 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% 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*. In control cells over a 3-day reproduction cycle, the melanoma cell number increased approximately 200%. At concentrations of stypoldione from 2 μg/ml to 16 μg/ml, melanoma growth was reduced at the lowest concentration and abolished at the highest concentration. Visual observations of the growing cells revealed that 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. There was little evidence of lysed cells at any concentration. Lower concentrations of stypoldione allowed growth to occur to some degree.

We conclude that this substance is worthy of further investigation into its anticancer potential. Special studies are planned to explore its site and mechanism of action. Stypoldione is of interest to other investigators active in cancer research. It has been shown to inhibit assembly of microtubules in Dr. Les Wilson's laboratory, and he and graduate students Tim O'Brien and Steven White are exploring its action in several systems. It is also active in the National Cancer Insititute screens. In my laboratory we are examining its effect on cell cycle kinetics in synchronously and asynchronously dividing cells. We are particularly interested in determining at what step(s) during cell division this type of compound may act. Since this represented a new area of research for my group, we devoted considerable time to developing cell culture techniques and evaluating standard drugs in which the mechanism of action is known. We found pharmacological specificity in some of the cell lines — particularly the fertilized sea urchin eggs (see Jacobs *et al.*, 1981).

Recent investigation by graduate student Tim O'Brien in Dr. Leslie Wilson's laboratory has shown that stypoldione is a fairly potent inhibitor of bovine brain assembly. Stypoldione inhibits the binding of the classical microtubule inhibitor colchicine to tubulin in a fashion that indicates binding at a separate site. In our laboratory, attempts to determine the precise point in the cell cycle at which stypoldione acts have shown that, in sea urchin eggs, stypoldione inhibits amino acid and nucleoside uptake, inhibits amino acid incorporation into protein, but does not inhibit nucleoside incorporation. This finding, along with the facts that microscopic evaluation shows no mitotic figures (in sea urchin eggs or in cells in culture) and that cell division is inhibited at concentrations lower than microtubule assembly, points to a site of action prior to mitosis but following S1 DNA synthesis. Investigation of the site and mechanism of action of stypoldione in the cell cycle and in microtubule assembly are continuing, and we have begun study of its newly discovered ability to inhibit sperm motility. At this point, stypoldione has strong potential both as an anticancer and as a spermicidal agent.

We have also begun specific study of the actions of the pseudopterolides, a group of compounds from *Pseudopterogorgia acerosa*. These compounds produce inhibition of cell division in a most unique manner — microscopy shows progression of synchronous nuclear division with *no* cytokinesis, producing cells with 2, 4, 8, 16 and more nuclei. Cytochalasins have been reported to produce cells with multiple nuclei, but not in such synchronous fashion and not without apparent disturbance of the cell membrane.

We have several active compounds from marine sources that we hope will prove useful as pharmacological probes. It is my plan to exploit these observations by investigating each compound and separating out those that may have a novel mechanism of action.

Cooperating Organizations
Bristol-Myers Corporation
National Cancer Institute

Publications

BLANKEMEIER, L. A. AND JACOBS, R. S. 1983. Biochemical analysis of the inhibition of purified phospholipase A_2 by the marine natural product, Manoalide. Federation Proceedings 42:374.

BURLEY, E. S. AND JACOBS, R. S. 1979. Effects of 4-aminopyridine on extra-cellular nerve terminal action potentials (NTAP) on frog sartorius muscle-sciatic nerve prepartation. The Pharmacologist 21:244.

BURLEY, E. S. AND JACOBS, R. S. 1981. Effects of 4-aminopyridine on nerve terminal action potentials. J. Pharm. Exp. Ther. 219:268-273.

BURLEY, E. S., SMITH, B., CUTTER, G., AHLEM, J. K., AND JACOBS, R. S. 1982. Antagonism of phorbol 12-myristate 13-acetate induced inflammation by the marine natural product, Manoalide. The Pharmacologist 24:117.

CULVER, P. AND JACOBS, R. 1979. Elevation of rat blood glucose induced by two diterpenes from the mollusc. The Pharmacologist 21:250.

CULVER, P. AND JACOBS, R. S. 1980. Inhibition of skeletal muscle contraction by a substance from soft coral. Federation Proceedings 37:927.

CULVER, P. AND JACOBS, R. S. 1981. Lophotoxin: a neuromuscular toxin from the sea whip (*Lophogorgia rigida*). Toxicon.

DEFREITAS, J. C., BLANKEMEIER, L. A., AND JACOBS, R. S. In prep. 1983. *In vitro* inactivation of the neurotoxic action of β-bungarotoxin by the marine natural product, Manoalide.

DEFREITAS, J. C. AND JACOBS, R. S. In press. 1982. Biotoxins in *Brachyuran* decapod crustaceans. 7th World Congress on Animal, Plant and Microbial Toxins.

DEFREITAS, J. C. AND JACOBS, R. S. 1983. Antagonism of the neurotoxic action of β-bungarotoxin on the rat phrenic nerve-hemidiaphragm by the marine natural product, Manoalide. Federation Proceedings 42:374.

FENICAL, W., OKUDA, R. K., BANDURRAGA, M. M., CULVER, P., AND JACOBS, R. S. 1981. Lophotoxin: a novel neuromuscular toxin from Pacific sea whips of the genus *Lophogorgia*. Science 212:1512-1514.

JACOBS, R. S. January 1982. How can we search for bioactive marine products?. Symposium AAAS.

JACOBS, R. S., CLASON, E. L., BURLEY, E. S., HOCHLOWSKI, J., AND FAULKNER, D. J. In prep. 1983. Inhibition of phorbol induced inflammation in the mouse ear by the marine natural product, Manoalide.

JACOBS, R. S., WILSON, L., AND WHITE, S. J. 1981. Selective cell division inhibitors derived from marine organisms: effects on cell division in fertilized sea urchin eggs. Federation Proceedings 40:26-29.

LANGDON, R. B. AND JACOBS, R. S. 1983. Quantal analysis indicates an d-toxin-like block by lophotoxin, a non-ionic marine natural product. Life Sciences 32:1223.

LANGDON, R. B. AND JACOBS, R. S. March 1982. Irreversible attenuation of amphibian neuromuscular junction endplate potentials (EPP's) by the marine natural product, Lophotoxin (LoTx). Federation Proceedings.

LANGDON, R. L. AND JACOBS, R. S. 1980. An inexpensive frequency modulated (fm) radio monitor of time dependent analogue paramenters. Methods in Pharmacology 3:191-190.

O'BRIEN, T., JACOBS, R. S., AND WILSON, L. In press. 1983. Inhibition of bovine brain microtubule assembly *in vitro* by stypoldione. Molecular Pharmacology.

O'BRIEN, T., JACOBS, R. S., AND WILSON, L. March 1982. *In vitro* effects of the marine natural product stypoldione on bovine microtubules. Federation Proceedings.

WHITE, S. AND JACOBS, R. S. 1981. Inhibition of cell division and of microtubule assembly by elatone, a halogenated sesquiterpene. Molecular Pharmacology.

WHITE, S. J. AND JACOBS, R. S. 1979. Inhibition of microtubular polymerization by the halogenated sesquiterpene elatone. The Pharmacologist 21:170.

WHITE, S. J. AND JACOBS, R. S. Submitted. 1983. Effects of Stypoldione on cell cycle progression, DNA and protein synthesis, and cell division in cultured sea urchin embryos. Molec. Pharm.

WHITE, S. J. AND JACOBS, R. S. March 1982. Inhibition of macromolecular synthesis, precurser uptake and cell division by the marine cytotoxin stypoldione. Federation Proceedings.

MARINE CHEMISTRY AND PHARMACOLOGY PROGRAM: CHEMICAL STUDIES OF TROPICAL MARINE ALGAE AND COELENTERATES

University of California, San Diego, Institute of Marine Resources
R/MP-22
1980-82

William H. Fenical

The Marine Chemistry and Pharmacology Program is a collaborative effort between investigators at three campuses of the University of California (San Diego, Santa Barbara, and Santa Cruz), aimed at biomedical investigation of marine natural products. The program consists of three chemists and one pharmacologist, and the strength of the program is the frequent and continual dialogue between investigators of different disciplines.

This project emphasizes the isolation of novel bioactive compounds from marine algae and from gorgonian and alcyonacean soft corals found mainly in tropical and subtropical habitats. The long-term goals of the Marine Chemistry and Pharmacology Program are to investigate marine natural products, assessing their physiological properties, and, where appropriate, to pursue the development of substances as new pharmaceuticals and research chemicals. The project is conducted in close affiliation with several pharmaceutical and agrichemical industries to allow commercial interest to guide developmental activities. Since 1980, more than ten potentially useful compounds have been discovered and three in particular continue along a progressive line toward being utilized as mentioned above.

Field Programs

An indispensible component of this project is the continuing procurement of marine specimens from various marine habitats. The success of this project depends upon the collection of large samples of marine organisms known to possess some form of unique biological activity and chemistry. In field activities, Professor Jacobs and I work closely together to make effective collections, and our collecting activities are usually guided by *in situ* biotesting of crude extracts. The decision to research tropical organisms was made based upon the higher levels of toxicity noted in these organisms, and fruitful yields have been recognized. Our main field programs are in the Gulf of California and in the Caribbean Sea; expeditions are made at least once each year. For the past 2 years we were fortunate to be able to utilize the University of Miami's *ORV CALANUS* in the Bahama Islands. While funded mainly by NSF, this collection was made on a "not to interfere" basis as part of another research project. In the past 2 years, over 200 specimens of Caribbean-based plants and animals were evaluated during this expedition. Extracts were tested onboard for antibacterial and antiyeast activity, for toxicity against insect larvae (*Tenebrio* larvae), and for gross effects upon intraperitoneal injection in mice. Numerous activities were discovered including several potent antibacterial extracts. One gorgonian coral, in particular, was found to be amazingly toxic. The need to recollect many of these has been realized.

Chemical Studies

Since the initiation of this project in 1980, numerous chemically unique and biologically active substances have been isolated from marine plants and animals. The algae have yielded several cytotoxic compounds with potential in the treatment of cancer. *Stypopodium zonale*, for example, gave the orthoquinone stypoldione (**1**) which inhibits cell division by the inhibition of tubulin polymerization (figure 1). From *Spatoglossum schmittii* we isolated another cytotoxin, spatol (**2**) possessing a unique diepoxide composition. The red alga *Liagora farinosa* yielded the toxic, acetylene-containing lipid **3**, and numerous phenolic antibiotics, such as **4**, were isolated from brown algae of the genera *Zonaria* and *Lobophora*.

Recent studies of tropical green algae have yielded several interesting new bioactive compounds. *Avrainvillia longicaulis* was found to produce the brominated diphenylmethane **5**, which shows antimicrobial activity. *Caulerpa bikinensis* was found to produce a series of cyclic toxins related to **6**, and numerous *Halimeda* species were found to contain the unique diterpenoid trialdehyde **7**. Compound **7** showed broad-screen antimicrobial activity and was found to inhibit sea urchin sperm motility at 10^{-7} M concentrations.

Studies of tropical coelenterates have also yielded interesting new secondary metabolites. The soft corals from Palau were investigated and *Clavularia inflata* was found to produce the toxic hydrocarbon **8**. The sea fans and whips, though, represented our most important resource for bioactivity leads. The Caribbean gorgonian *Erythropodium caribaeorum* yielded the unique diterpenoid **9** while numerous *Pseudopterogorgia* species have been found to produce diterpenoid pentosides related to **10**. *Eunicea calyculata* has been found to possess diterpenoids of several unique types. Bicyclic compounds such as **11** are produced, along with monocyclic compounds (**12**) of the novel cubitene ring system. Several of these latter substances show cytotoxic and anti-inflammatory activity.

From Pacific Ocean sea fans and whips, we have isolated several new compounds over the last year. *Muricea fruticosa* has yielded a group of exceptional amino-galactose saponins, such as **13**, which vary as to their nature and degree of esterification. These compounds showed initial activity in the neuromuscular preparation. Several new substances have been described from *Pacifigorgia* species. Two examples are the lactone **14** and the rearranged diester **15**, which are now being biotested. *Pacifigorgia adamsii* was found to produce the toxic alcohol **16**, which showed selective toxicity only toward fish.

Developmental Investigations

The results of this project are now

sufficient that significant time is being invested in the advanced study and development of several bioactive natural products. Stypoldione (**1**) is being prepared for patenting through UC based upon its novel mechanism of cytotoxic action. Stypoldione is active (T/C = 140) in the National Cancer Institute's P-388 Leukemia assay. Elatol (**17**), another cytoxic agent, is also still in developmental stages. Five other compounds have been retained based upon their cytoxic properties.

Our most exciting discoveries during the past year have dealt with the chemistry of gorgonian corals from both Pacific Mexico and the Caribbean Sea. An investigation of the toxic sea whip *Lophogorgia rigida* resulted in the isolation of a potent nonprotein neurotoxin we called lophotoxin (LTX). LTX (**18**) shows irreversible neuromuscular blockade (figure 2) in the isolated rat hemidiaphragm-phrenic nerve preparation with concentrations as low as 10^{-6} Molar. This compound is as toxic as snake venoms but possesses an unrelated structure.

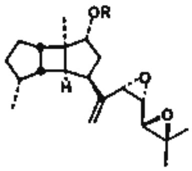
This compound may possess beneficial activities below the toxic dose and this possibility is under investigation. The potential for LTX to be a useful research tool is also quite high. Along with lophotoxin we isolated a series of related compounds (**19-23**), each of which shows some activity in the phrenic nerve preparation. Since the theories to explain neurotoxicity involve the proximity of nitrogen atoms in numerous toxin models, LTX, which lacks nitrogen, may cause revisions in the accepted theories.

Nationwide, four independent laboratories are studying various facets of the pharmacology of LTX designed to define its unique mechanism of neuromuscular toxicity. Chemical synthesis is also in progress in at least one laboratory. Lophotoxin appears to be a very useful probe for physiological studies of nerve transmission. We have received numerous requests to supply this interesting compound, and to date we have done so. However, this situation has reached a point where it is affecting our basic research, and efforts have been made to subjugate this activity to a major biochemical company.

Studies of the purple sea plume, *Pseudopterogorgia acerosa*, from the Caribbean Sea, have yielded a very potent inhibitor of cell division. This compound, called pseudopterolide (**24**) (figure 3), inhibits overall cell cleavage in the fertilized urchin egg assay (figure 4), but it does not inhibit nuclear division. This effect has been previously noted in the unusual fungal metabolite cytochalasin-D, which has been highly used in cell research. The effects of this compound in other assays and against cancer cells remain to be determined. Pseudopterolide possesses an unusual carbon skeleton that has not been observed as a natural product.

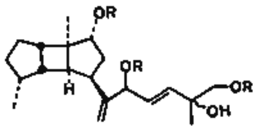
The Pacific gorgonia *Pacifigorgia adamsii* has yielded a potential ichthyotoxin which we have assigned as structure **25** (figure 3). This compound, which we refer to as pacifigorgiol, seems to possess specific toxicity exclusively toward fish, and the structure of this toxin is unique among the rearranged sesquiterpenoids. It is, indeed, uncommon to find such potent toxicity from such a simple molecule. A series of chemically related substances from related gorgonians of the genus *Pacifigorgia* are under current investigation.

Lastly, an investigation of the stoloniferan coral *Clavularia inflata* has yielded another toxin of an unprecedented type. The C_{12} hydrocarbon **26** (figure 3) was found to comprise over 5% of the dry weight of *C. inflata* and to possess ichthyotoxic properties in the 5 μgm/ml range. It appears that a compound of this type must be a degradation product of a larger terpenoid precursor. More extensive testing of these fish toxins is in progress.



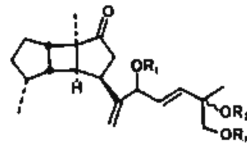
R = H

1



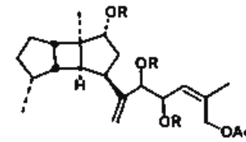
R = H

2



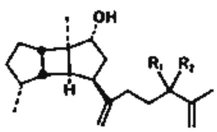
$R_1 = R_2 = H$

3



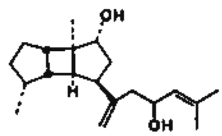
R = H

4

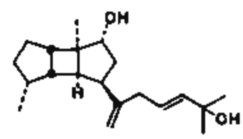


$R_1 = H$; $R_2 = OH$
$R_1 = OH$; $R_2 = H$

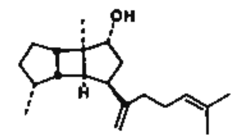
5, 6



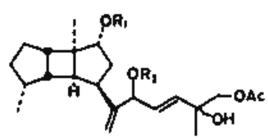
7



8

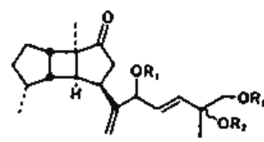


9



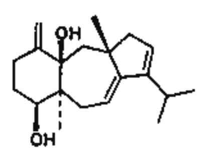
$R_1 = R_2 = H$

10

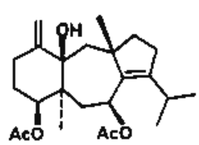


$R_1 = R_2 = H$

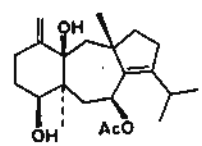
11



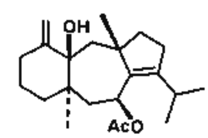
12



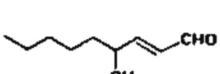
13



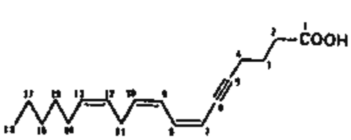
14



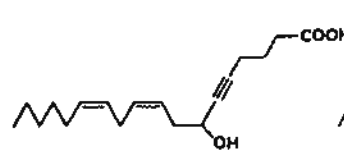
15



16

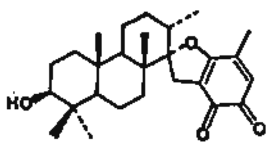


17

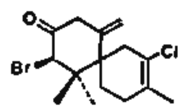


18

19

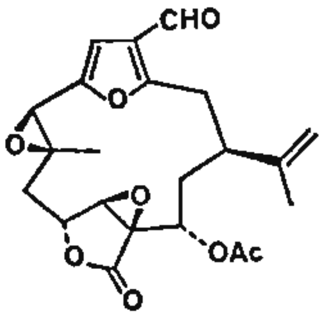


20



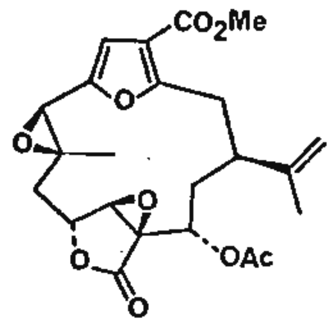
21

Figure 1. Compounds isolated from marine algae.



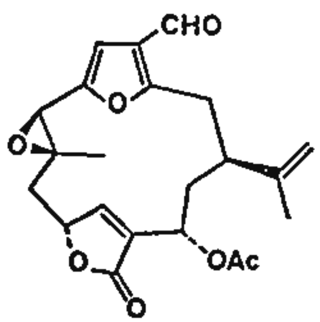
1000

lophotoxin (22)



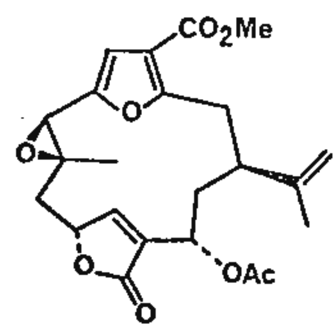
90

lopholide A (23)



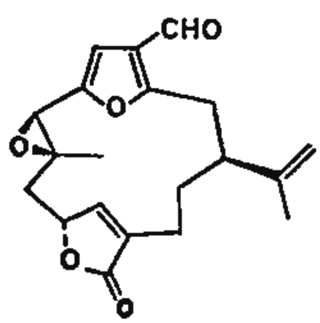
90

deoxylophotoxin (24)



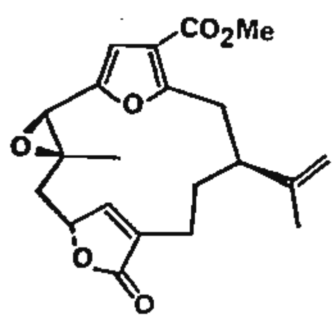
250

acetoxypukalide (25)



20

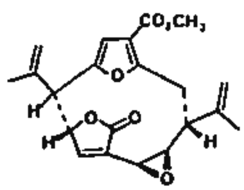
pukalide aldehyde (26)



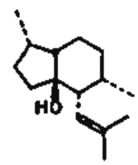
2

pukalide (27)

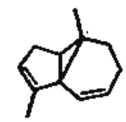
Figure 2. Neuromuscular activity relative to lophotoxin.



28



29

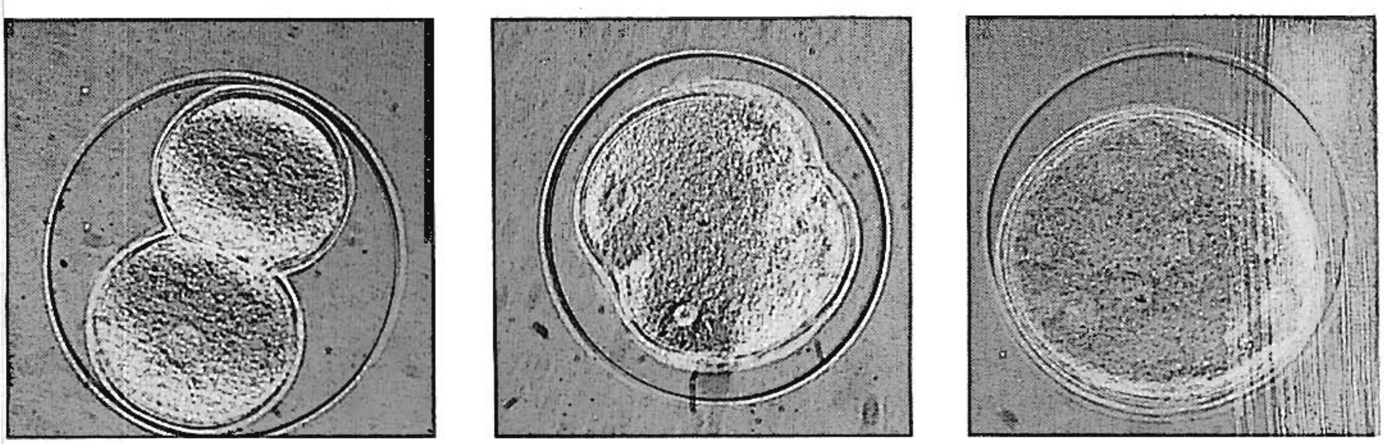


30

Figure 3. Compounds isolated from marine soft corals.

CONTROL

TREATMENT WITH PSEUDOPTEROLIDE (5μg/ml)



NORMAL CELL DIVISION

INHIBITION OF CELL CLEAVAGE - 4 NUCLEI

16 NUCLEI

Figure 4. Inhibition of sea urchin egg cleavage by pseudopterolide.

Cooperating Organizations
FMC Corporation
Lilly Research Laboratories
National Cancer Institute
Syntex Laboratories

Publications

FENICAL, W. 1981. The expanding role of marine organisms in anticancer chemotherapy. In *Biosaline research*, A. San Pietro, ed. Plenum Press, Inc.

FENICAL, W., OKUDA, R. K., BANDURRAGA, M. M., CULVER, P., AND JACOBS, R. S. 1981. Lophotoxin: a novel neuromuscular toxin from Pacific sea whips of the genus *Lophogorgia*. Science 212:1512-1514.

GERWICK, W. AND FENICAL, W. 1982. Phenolic lipids from related marine algae of the order Dictyotales. Phytochemistry 21:633-637.

GERWICK, W. H., ENGEN, D. VAN, AND CLARDY, J. 1980. Isolation and structure of spatol, a potent inhibitor of cell replication from the brown seaweed *Spatoglossum schmittii*. J. Am. Chem. Soc. 102:7991-7993.

GERWICK, W. H. AND FENICAL, W. 1981. Spatane diterpenoids from the tropical marine alga *Stoechospermum marginatum* (Dictyotaceae). J. Org. Chem. 46:2233-2241.

IZAC, R. R., BANDURRAGA, M. M., WASYLYK, J. M., DUNN, F. W., AND FENICAL, W. 1982. Germacrene derivatives from diverse marine soft-corals (Octocorallia). Tetrahedron 38:301-304.

PAUL, V. J. AND FENICAL, W. 1980. Toxic acetylene-containing lipids from the red marine alga *Liagora farinosa* Lamouroux. Tetrahedron Lett. 21:3327-3330.

SUN, H. H., MCCONNELL, O. J., FENICAL, W., HIROTSU, K., AND CLARDY, J. 1981. Tricyclic diterpenoids of the dolastane ring system from the marine alga *Dictyota divaricata*. Tetrahedron 37:1237-1242.

MARINE CHEMISTRY AND PHARMACOLOGY PROGRAM: CHEMISTRY OF SPONGES AND OPISTHOBRANCH MOLLUSCS

University of California, San Diego
R/MP-23
1980-82

D. John Faulkner

During the past year we made major collections in Palau, Western Caroline Islands, and in the Gulf of California. The primary purpose of the Palau expedition was to collect further samples of the sponge that contained JF-133, a potent anti-inflammatory agent. We succeeded in this task and obtained a 5-cu. ft. box of frozen sponge. This will provide enough JF-133 to complete the evaluation by Dr. Jacobs and to supply samples to pharmaceutical companies for their evaluation as a potential new drug. We are also performing some simple reactions on JF-133 in order to prepare an active derivative that will allow a stronger patent position to be obtained should JF-133 have commercial potential.

We collected a total of 126 sponge samples in Palau. The crude extracts have been screened against seven microorganisms and in an assay for inhibition of cell division in the fertilized sea urchin egg. Fifty-six of the crude extracts showed antimicrobial activity, generally against Gram-positive bacteria. In the sea urchin assay, 42 methanolic extracts inhibited cell division at 200 μg/ml in seawater. These samples were partitioned between dichloromethane and water. Nine aqueous extracts were active at 100 μg/ml in seawater, 9 dichloromethane extracts were active at 10 μg/ml, and a further 10 dichloromethane extracts were active at 50 μg/ml. We have assigned a high priority to 16 samples that will be studied during the next year.

Chemical studies on Palau sponges have resulted in the isolation and identification of polybrominated diphenyl ethers from *Dysidea herbacea, Dysidea chlorea*, and *Phyllospongia foliascens.* The polybrominated diphenyl ethers inhibited the growth of both Gram-positive and Gram-negative bacteria. Our sample of *D. herbacea* contained two known compounds and 2-(2',4'-dibromophenoxy)-3,5-dibromophenol (**1**). *D. cholorea* contained only 2-(2',4'-dibromophenoxy)-4,6-dibromophenol (**2**). *P. foliascens* contained 2-(3',5'-dibromo-2'-methoxyphenoxy)-3,5-dibromoanisole (**3**), 2-(3',5'-dibromo-2'-hydroxyphenoxy)-3,5,6-tribromophenol (**4**), and 2-(3',5'-dibromo-2'-hydroxyphenoxy)-3,4,5,6-tetrabromophenol (**5**). Since tetrachlorodioxin was known to be extremely toxic, we prepared 3,5,4'-tribromodioxin (**6**). The brominated dioxins could not be detected in the sponge and we have since been informed by Dr. J. T. Baker that "they are not regarded as particularly toxic."

We are particularly interested in γ-hydroxybutenolides since they seem to have very interesting pharmacological properties. Two unidentified sponges from the 1979 Palau collection contained sesterterpenes with the γ-hydroxybutenolide group at one terminus. The sesterterpene (**7**), identified from spectral data only, was obtained in very small quantities. The second sesterterpene (**8**) was identified by interpretation of spectral data and by a chemical interconversion with illimaquinone (**9**). Both compounds **7** and **8** inhibited the growth of Gram-positive bacteria and compound **8** is undergoing evaluation at UC Santa Barbara.

Our interest in sponges that burrow into calcareous substrates led to an investigation of an unidentified *Siphonodictyon* sp. found in coral heads at Palau. The major antimicrobial metabolite was a sesquiterpene **10** having a guanidine functionality. The identification was based on interpretation of spectral data of the compound and a stable derivative. The corresponding alcohol **11** was a minor metabolite of the sponge. The sesquiterpene **10** is being screened by Dr. Jacobs at UC Santa Barbara.

During the last year we supplied a total of 25 pure compounds and 24 crude extracts for evaluation. Twelve of the pure compounds are minor constituents of the sea hare *Dolabella californica* and five are metabolites of the sponge *Reniera* sp. The results of the evaluations will be presented by Dr. Jacobs (R/MP-21).

We have recently found some interesting metabolites that are thought to be responsible for the lack of fouling organisms on the San Diego sponge *Toxadocia zumi.* These compounds are sulfated sterols with the general structure **12** where R represents a mixture of common sterol side chains. The sponge contained three steroidal sulfates (**13-15**) having a carboxylic acid group in place of the usual methyl group at C-19. These compounds are strongly antimicrobial and inhibit cell division in the fertilized sea urchin egg assay. It is rare to find a new class of sterol, particularly one with such pronounced biological activity.

The 1981-82 period has been one of consolidation. We have emphasized research aimed at developing new potential pharmaceuticals from natural products having interesting pharmaceutical properties. Fewer compounds have been submitted for broad pharmacological screening but, for the first time, these have included semisynthetic compounds prepared from natural products having promising pharmacological activity. Research on isolation and structural elucidation has emphasized the identification of the more polar natural products which appear to possess greater biological activity.

Research on manoalide (**16**) by Dr. Jacobs and his group has indicated that it is a nonsteroidal anti-inflammatory agent having activity comparable to that of cortisone. In order for Dr. Jacobs to pursue studies of the mode of action of manoalide (**16**), we have devised a very short method of isolation that enables manoalide to be isolated rapidly and in high yield from crude extracts of the sponge *Luffariella variabilis.* We have also prepared several semisynthetic derivatives of manoalide, one of which appears to be a superior anti-inflammatory agent. Further testing of the derivatives is anticipated.

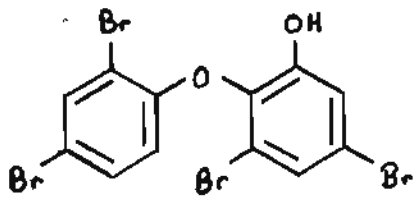
The isolation of the renieramycins A-D (**17-20**) is proving to be a most interesting discovery. The renieramycins are closely related to the saframycins, a group of antitumor antibiotics from the microorganism *Streptomyces lavendulae*. Research on the saframycins has been underway for several years and interest in that group of compounds is still increasing. We have recently been able to supply samples of renieramycin A to groups that have previously studied the saframycins. If their results indicate a similar mode of action, we expect to develop our research on the renieramycins using saframycin research as a model. Our major problem at present is to obtain more material.

We have isolated a number of new marine natural products during the past year, but some of these were obtained in quite small quantities. However, the structures are of sufficient interest to warrant recollection and re-isolation for the screening program.

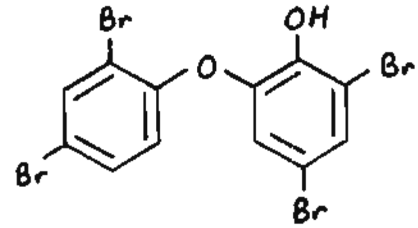
The tambjamines (**21-24**) were isolated from the nembrothid nudibranchs *Tambje eliora*, *Tambje abdere*, and *Robostra tigris* during a study of defensive behavior of the nudibranchs. Hydrolysis of the non-brominated compounds **21** and **23** gave an aldehyde **25** that had previously been prepared as an intermediate in the synthesis of the antibiotic prodigiosin. Initial screening has revealed that all of these compounds (**21-25**) inhibit cell division in the fertilized sea urchin egg assay at 1μg/ml in seawater. The isobutylamines **23** and **24** showed antimicrobial activity against *C. albicans, S. aureus, B. subtilis*, and *V. anguillarum* at 5 μg/disc.

The antimicrobial activity of *Agelas mauritiana* was found to be due to diterpenoid bases of which the purine derivative **26** is an example. This is the first diterpenoid base to be completely described. We have to re-isolate this and other related compounds for pharmacological screening.

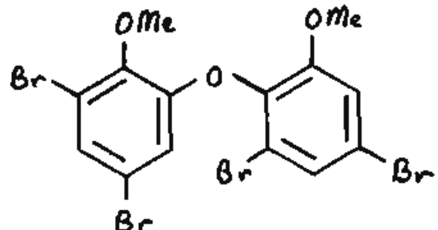
The first marine natural product containing a brominated furan moiety has been isolated from the sponge *Dendrilla* sp. collected in Palau. The brominated diterpene **27** is one of a series of diterpenes under investigation by Brian Sullivan.



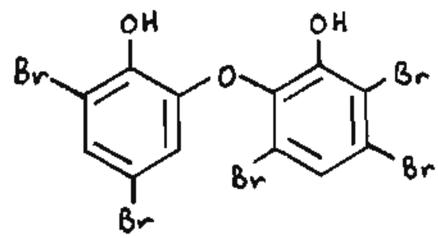
1



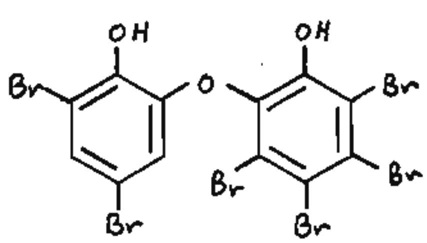
2



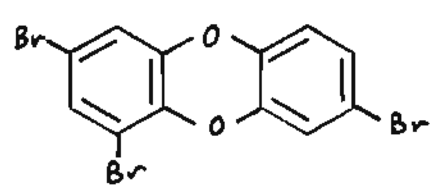
3



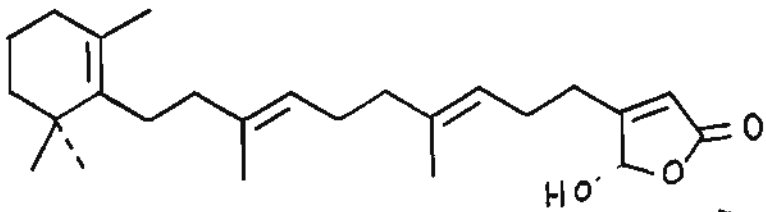
4



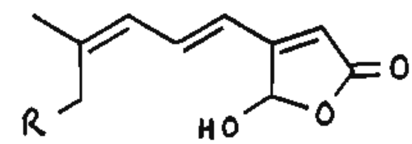
5



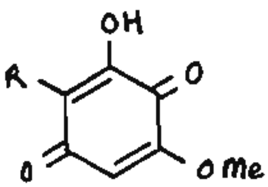
6



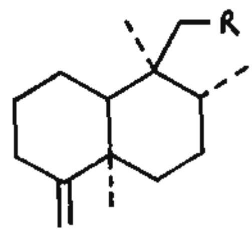
7

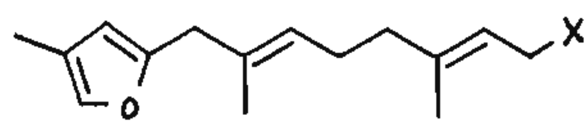


8

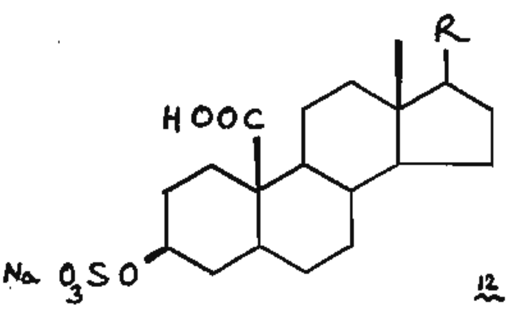


9

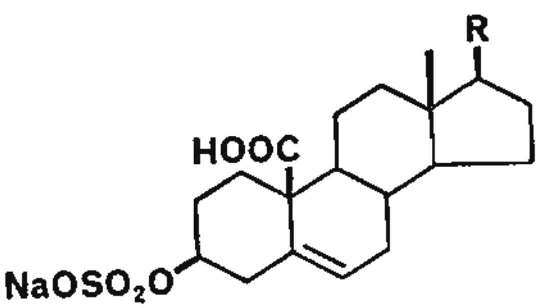


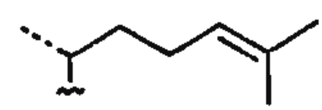


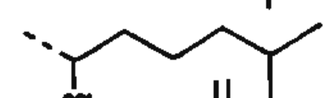
10	X =	$-NH-C(=NH)-NH_2$
11	X =	$-OH$

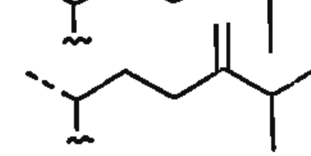


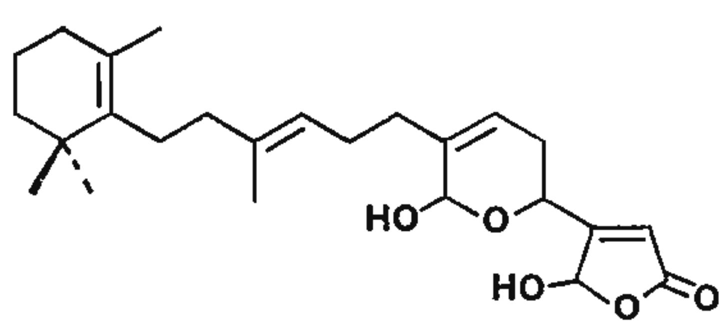
12



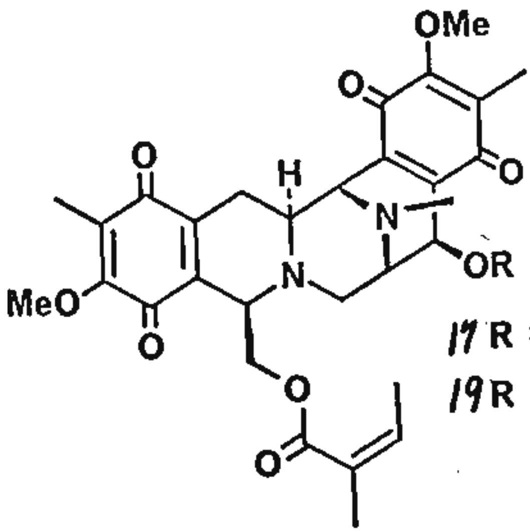
13 R = 

14 R = 

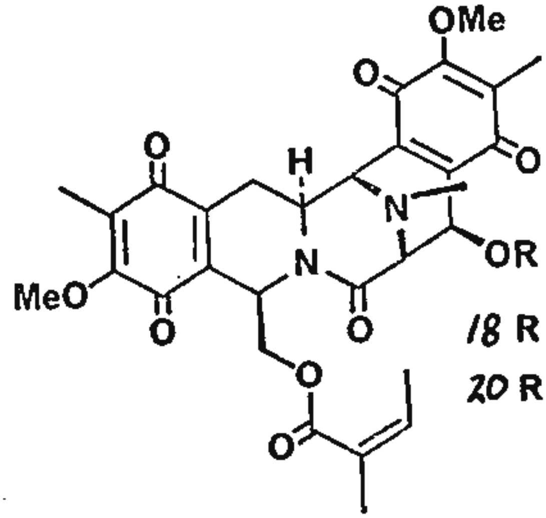
15 R = 



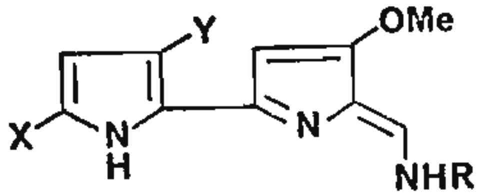
16



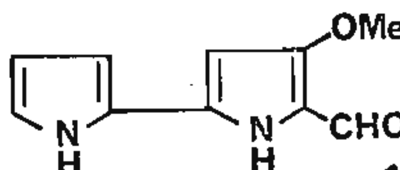
17 R = H
19 R = Et



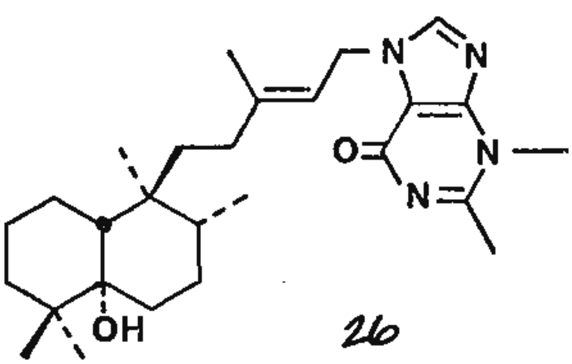
18 R = H
20 R = Et



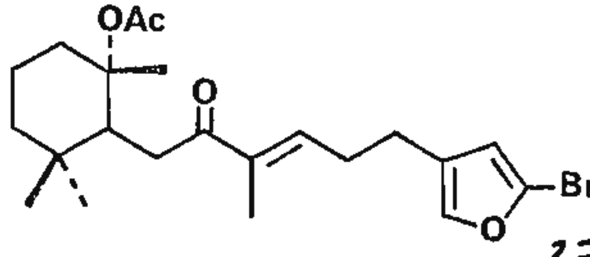
21 X = H Y = H R = H
22 X = Br Y = H R = H
23 X = H Y = H R = *i*-Bu
24 X = H Y = Br R = *i*-Bu



25



26



27

Cooperating Organizations
Lilly Research Laboratories
Syntex Corporation

Publications

CARTÉ, B. AND FAULKNER, D. J. 1981. Polybrominated diphenyl ethers from *Dysidea herbacea, Dysidea chlorea* and *Phyllospongia foliascens.* Tetrahedron 37:2335-2339.

FRINCKE, J. M. AND FAULKNER, D. J. 1982. Antimicrobial metabolites of the sponge *Reniera* sp. J. Amer. Chem. Soc. 104:165.

NAKATSU, T., RAVI, B. N., AND FAULKNER, D. J. 1981. Antimicrobial constituents of *Udotea flabellum.* J. Org. Chem. 46:2435-2438.

STIERLE, D. B. AND FAULKNER, D. J. 1980. Metabolites of the marine sponge *Laxosuberites* sp. J. Org. Chem. 45:4980-4982.

SULLIVAN, B. AND FAULKNER, D. J. 1982. An antimicrobial sesterterpene from a Palauan sponge. Tetrahedron Lett. 907.

WALKER, R. P. AND FAULKNER, D. J. 1981. Chlorinated acetylenes from the nudibranch *Diaulula sandiegensis.* J. Org. Chem. 46:1475-1478.

WALKER, R. P. AND FAULKNER, D. J. 1981. Diterpenes from the sponge *Dysidea amblia.* J. Org. Chem. 46:1098-1102.

WALKER, R. P., THOMPSON, J. E., AND FAULKNER, D. J. 1980. Sesterterpenes from *Spongia idia.* J. Org. Chem. 45:4976-4979.

MARINE CHEMISTRY AND PHARMACOLOGY PROGRAM: NATURAL PRODUCTS FROM TOXIC MARINE ORGANISMS

University of California, Santa Cruz
R/MP-24
1980-82

Phillip Crews

The ocean's natural resources and natural phenomena continue to provide important stimuli to basic and applied research. Marine organic chemistry represents an important area of inquiry in which both of these apply. We are studying the organic chemistry of a select group of organisms as sources of new biologically active substances. That this is a worthwhile pursuit can be illustrated by recent, widespread interest on the potential of drugs from the sea: see for example, D. J. Faulkner, Oceanus 22, No. 2, pp. 44-50 (1979), or "The Pharmacology of Marine Natural Products — A Symposium," Federation Proceedings, 40, 7-36 (1981). It is also significant that this subject has captured the interest of the Under Sea Medical Society: it was a focus of a recent special workshop entitled "Collection and Analysis of Biologically Active Material from the Sea," UMS publication #37 (8/15/80).

Our major goal is to systematically explore the pharmacological potential of organic natural products from soft-bodied invertebrates, in particular sponges. Bakus (Science, 211:497, 1981) has pointed out that tropical coral reef soft-bodied organisms seem to have evolved chemical defense mechanisms for protection against predators and grazers. Our past chemical work on such organisms (Crews *et al.*, 1981) agrees with this. Moreover, some valuable leads have been uncovered by bioactivity results on marine natural products that we have isolated since this project began.

During the last few years we have devoted considerable effort to collecting and identifying promising samples, which are summarized in table 1. Our focus has been upon three rather different coral reef areas. These include the Caribbean Honduras Bay Islands, islands in south Pacific Tonga group, and sites in French Polynesia. We have implemented an effective procedure which involves collection of an organism followed by immediate extraction (dichloromethane) and subsequent concentration of its oil. A further operation involves partitioning active extracts between a hexanemethanol (1:1) mixture which is followed by purification via standard preparative chromatography methods. Purified compounds (PC) such as **1, 9, 11, 17, 20, 22, 43, 52, 68, 69, 82** (see report R/MP-21) have been identified as having interesting activity. Work now in progress should reveal the exact structures of PC-43, 68, 69, and 82, whereas the structures of the rest are known.

Algae

Mixed collections of two toxic brown seaweeds, *Dictyota linearis* and *D. divaricata* were studied from five collection sites in the Honduras Bay Is. Two known dolastane diterpenes were isolated, while five new ones (**1-5**) were also characterized. A combination of carbon-13 and proton nuclear magnetic resonance experiments or chemical correlations supported structural and stereochemical assignments. Several of these metabolites showed pharmacological activity. Diol **6** at 16 μg/ml exhibited 71% reversible histamine antagonism on guinea pig ileum preparations. Compound **1** showed a 27% increase of the twitch height at 16 μg/ml in a rat hemidiaphragm preparation, while **4** showed a 48% decrease at the same concentration. This latter compound also exhibited a 17% inhibition of cell division in an urchin egg assay.

Some especially interesting chemical comparisons are evident based on the above results. The close similarity between natural products such as **1**, known from seaweeds and herbivorous molluscs (e.g., compound **7**), is not surprising. The urchin egg cell division inhibition activity seems also to correlate with the antileukemia activity reported for crude extracts containing compound **7** (Pettit, 1976).

Sponges

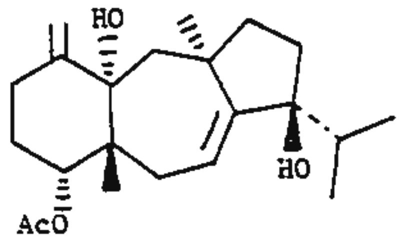
A very abundant south Pacific sponge, *Heteronemia* sp., has attracted our attention because it yielded a sesterterpene that shows 100% urchin egg cell division inhibition at 16 μg/ml. Its structure was secured as **8** and work in progress should reveal other bioactive minor metabolites.

A crude extract of a mixed collection of two color forms of *Phyllospongia* sp. from Tonga Is. shows 100% urchin egg cell division inhibition at 1 μg/ml. Bioassay-directed isolation experiments have yielded a semipure crystalline fraction which is a mixture of three compounds which are aromatic polybromides. A new collection yielded the pure **9** whose activity in the urchin assay is being further explored. Work in progress on active extracts from a dozen other south Pacific sponges should reveal additional fascinating new active natural products.

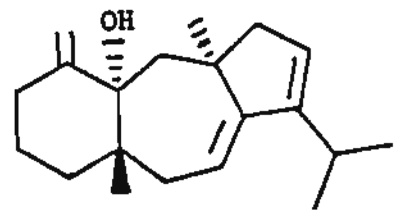
Toxic marine sponges are of particular interest to us. As an example, a Tongan sponge, BD-I-1, has extract fractions with 100% inhibition of urchin egg cells at 16 μg/ml. A hexabromophenyl ether **10** (PC-102) has been purified from this extract and submitted for additional assay. Various debromo analogs are being prepared for further evaluation of this potent bioactivity. Another Tongan sponge, DA-I-7, exhibited 100% ionotropy, which was reversible, in the frog ventricle strip assay (again, see report R/MP-21). Compound **11** (PC-52) has been identified as the major secondary metabolite in that extract. It, along with synthetic analogs **12** (PC-96) and **13** (PC-103), has been submitted for further evaluation. A rather abundant red Tongan sponge, DM-I-1, has displayed mild activity in three assays (see table 1) and its crude extract contains chiral ether glyceride **14** (PC-100). This compound (positive ichthyotoxicity at 400 μg/ml) along with its enantiomer **15** (PC-99) has been synthesized and submitted for further testing. Stimulated by the success with crude extracts, we anticipate that pure compounds will show a similar high percentage of actives in anti-inflammatory assay (table 1). In order to explore this we have resubmitted 12 pure compounds for assay in this area and suggested that another four compounds on hand be evaluated. If the results are encouraging here, we can obtain additional samples of 15 other pure compounds for similar evaluation.

Soft Corals

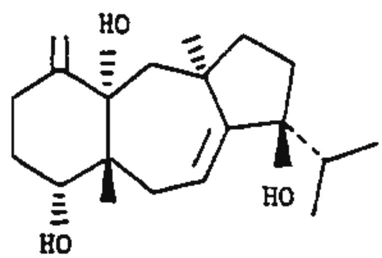
Our work has continued on the toxic extracts of the common Caribbean gorgonian *Briareum asbestinum*. A new asbestinin, **16**, was isolated and characterized, and this compound was of interest because of the biogenetic information that it supplied. In addition, this compound along with several other asbestinins mentioned in our report last year showed activity in the sea urchin anticell division assay.



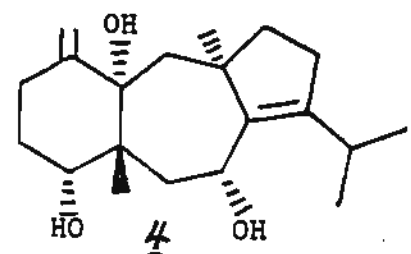
1



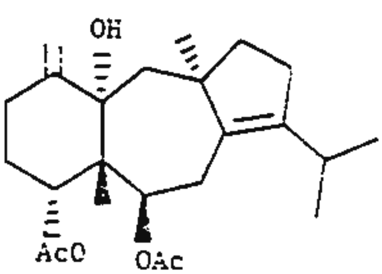
2



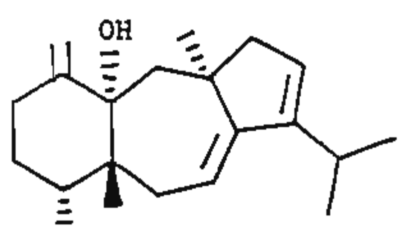
3



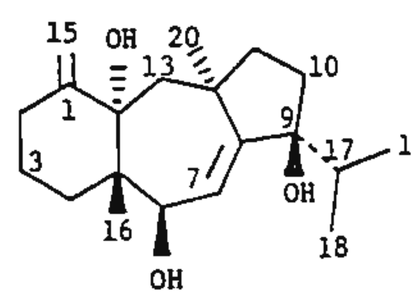
4



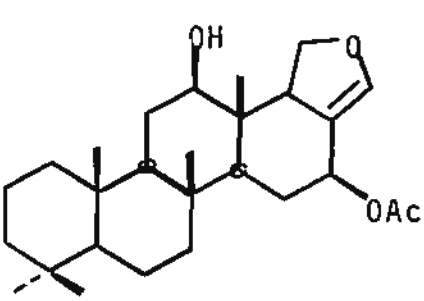
5



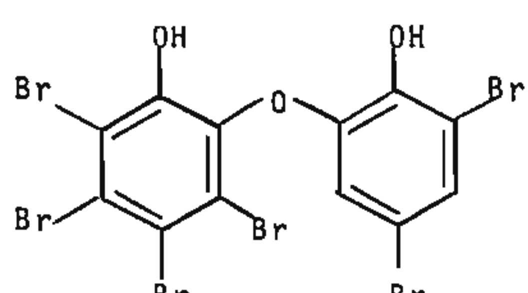
6



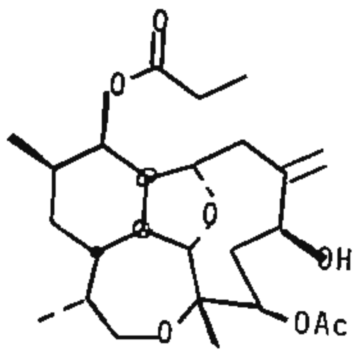
7



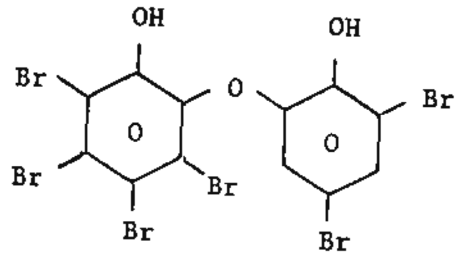
8



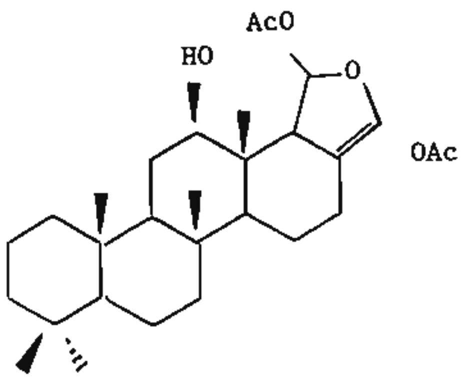
9



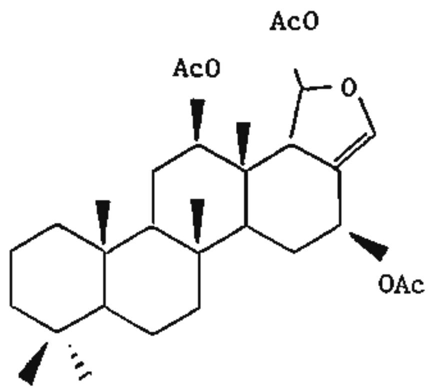
10



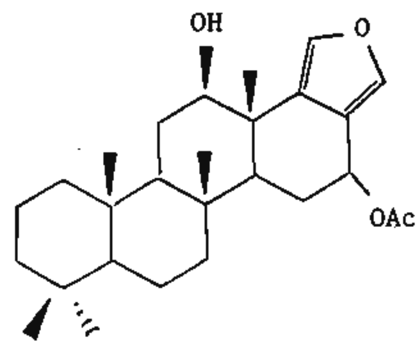
10



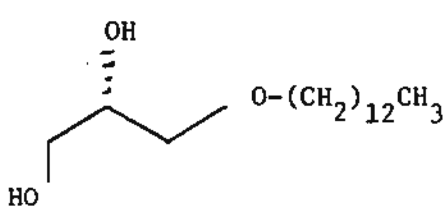
11



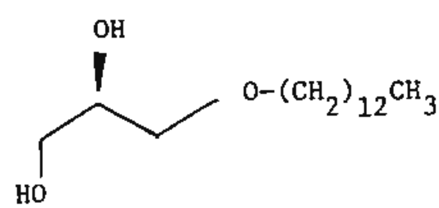
12



13



14



15

Table 1

Summary of Pharmacological Activity

Sample	Coll. #	Frog Ventricle Strip	(PMA) Mouse Ear (Infl)	Sea Urchin Egg (% Inh)	GF Auricles/ Ileum
09	OCTARIENE			76	W GPI
11	PACIFENOL			100 (ed= 4.5)	W GPI
17	DIHYVIOL			-	155 GPA
(38)	A. FULVA			100	- GPI/A
42	APLYS-1			-	100 GPA
43	CPD-A-44			100	69 GPA
(44)	BD-I-LB			65	+ GPI
(45)	BD-I-1C			100	100 GPI
(58)	BG-III-1A			-	100 GPI
(63)	BJ-IIC			51	100 GPI
69	CPD-A-65			100	+ GPI
(76)	DA-I-1	+	-	51	
(77)	DA-I-2	-	+32	-	
(78)	DA-I-3	+10/-19	+60	100	
(79)	DA-I-4	+	-20	-	
(80)	DA-I-7	100(R)	-48	21	
(81)	DB-I-1	+	-52	-	
82	x-tals-81	-	-27	-	-
(83)	DC-II-1	-	-1.5	-	
(84)	DD-I-1	-	-7	-	
(85)	DE-I-1	+	-9	-	
(86)	DE-I-2	+	-	-	
(88)	DG-V-1	-	-16	100	
(89)	DM-I-2	+	-5	7	
(90)	DL-III-	+	-5	-	
(92)	DM-I-1	-	-12	21	
(93)	DM-I-3	-	-	6	
(94)	DM-I-4	-	-	11	
(95)	DM-I-5	-	+13	-	
96	synthetic	+	-3	-	-

() extracts, others are pure compounds

Cooperating Organizations

National Science Foundation
Syntex Corporation
University of California Research Expeditions Program

Publications

CREWS, P., HANKE, F. J., NAYLOR, S., HOGUE, E. R., AND BRASLAU, R. 1983. Halogen regiochemistry and substituent stereochemistry determination in marine monoterpenes by ^{13}C NMR. J. Org. Chem. 48. (accepted for publication).

CREWS, P., KLEIN, T. E., HOGUE, E. R., AND MYERS, B. L. 1982. Tricyclic diterpenes from the brown marine algae *Dictyota divaricata* and *Dictyota linearis*. J. Org. Chem 47:811.

CREWS, P., SELOVER, S. J., TAGLE, B., AND CLARDY, J. 1981. New diterpenes from the common Gorgonian *Briareum asbestinum* (Pallus). J. Org. Chem. 46:964-970.

KANE, V. V., MARTIN, A. R., PETERS, J. A., AND CREWS, P. 1983. Carbon-13 NMR spectra of Cannabichromene, Cannabicyclol, Cannabicitran and their analogs. J. Org. Chem. 48. (accepted for publication).

MYERS, B. L. AND CREWS, P. 1983. Chiral ether glycerides from a marine sponge. J. Org. Chem. 48. (accepted for publication).

NAYLOR, S., HANKE, F. J., MANES, L. V., AND CREWS, P. 1983. Chemical and biological aspects of marine monoterpenes. Progress in the Chemistry of Org. Natural Prods. 43. (accepted for publication).

SELOVER, S. J. AND CREWS, P. 1980. Kylinone, A new sesquiterpene skeleton form the marine alga, *Laurencia pacifica*. J. Org. Chem 45:69-72.

OCEAN TECHNOLOGY

EARTHQUAKE-INDUCED FORCES ON NONAXISYMMETRIC OFFSHORE STRUCTURES

University of California, Berkeley
R/OT-1
1980-82

Robert L. Wiegel, William C. Webster,
Joseph Penzien, and Ben C. Gerwick, Jr.

Introduction

The reliable analysis of seismic loading on large offshore structures is a subject of considerable interest and effort. This is because of the probability that more of these structures will be placed in earthquake-prone areas off the California coast and in other similar regions such as the Gulf of Alaska. Under some conditions earthquake-induced foundation forces are very large, greater even than those induced by a 30-meter, 15-second wave. Owing to uncertainties associated with the design of large gravity structures for these conditions, and since there is little or no field data for reference to problems that are unique to this particular case, safe design is often an economic over-design owing to large safety factors being used in the design.

One major area of uncertainty has been the nature of the fluid-structure interaction and, in particular, the characteristics of the inertia forces on large-diameter submerged tanks and caissons due to earthquake excitation. The focal point of a previous Sea Grant study (R/E-14), which was begun in September 1976 and which was completed last year, was axisymmetric structures. The first 2 years of the program concentrated on defining the forces on a representative structure by tests made with a physical model of the large bottom portion (oil storage) of a gravity structure, using the University of California Berkeley (UCB) earthquake simulator. The model was constructed to a scale such that its foundation characteristics could be varied and its dynamic properties accurately measured. A numerical model with a computer program, using the finite element method, was developed to calculate the hydrodynamic pressure and added mass of a rigid submerged caisson subjected to a horizontal, harmonic ground excitation.

This data yielded a great deal of information about the magnitude, frequency dependence, and coupling of the inertia force coefficients relating to submerged tanks and caissons. The initial results of this study were published in a Ph.D. thesis by Robert C. Byrd in May 1978. A 1-year extension of the project (1978-79) was obtained to continue the analysis of the existing data, and to perform additional tests with a modified version of the physical model. After the tests with the model of the base had been completed, data reduced, and the results compared with existing theory, it became evident that a new direction was needed in regard to the physical model. This occurred many months after the renewal proposal had been submitted and accepted by Sea Grant. A large-scale model of the large-diameter surface-piercing cylinders was needed. That is, an array was needed that could be modified in configuration and in spacing between individual cylinders. This was necessary in order to measure the total array.

The new model required a modification of the surface plate, which was done. It was necessary to design and fabricate several circular cylinders, one of which was an instrumented model with strain cells, accelerometers, and pressure gages mounted inside it. Upon completion, the instruments were calibrated, and many tests run. The data were reduced. An additional 1-year extension permitted the completion of this work and the completion and testing of the numerical model.

The experimental results were adequate to determine the relative effects of axisymmetric and nonaxisymmetric structures. However, a design flaw in the system made it impossible to obtain data of sufficient reliability to make it worthwhile to proceed with expensive detailed analysis of the data. This three-dimensional effect is very difficult to handle analytically. A comprehensive analysis of the load cell portion of the model and the results obtained from a series of experiments on the earthquake simulator revealed that the second-order effects being studied were such that a modification of the load cells was required. A new design was completed and tested by a numerical model. The new model was constructed, under a no-cost extension of R/E-14, tested in the laboratory, and found to be satisfactory. Owing to scheduling difficulties with the earthquake simulator, a further no-cost extension was obtained, and tests were made on the earthquake simulator for the axisymmetric case.

The work that was done on this previous grant resulted in the development and testing of a numerical model that is adequate for the prediction of earthquake-induced loads on an axisymmetric large offshore gravity structure. This was published in a second Ph.D. thesis by Fukij Nilrat in May 1980. A companion Ph.D. thesis by Wataru Kioka was published in April 1980 (unsupported thesis). This work is not adequate, however, for the calculation of earthquake-induced loads on nonaxisymmetric structures, as was shown by the last series of tests made with the physical model.

Present Project

The overall objective of the present project (R/OT-1) is to provide a rational basis by which the offshore industrial and regulatory agencies can assess the safety of proposed nonaxisymmetric large offshore structures subjected to earthquake-induced loads. The laboratory portion of this project was delayed, because it was based upon the assumption that the instrument package used in Project R/E-14 would be operational, which it was not. This was discussed earlier.

A physical model study of the behavior of structure components immersed in water was performed during May and June 1981 using 1:200-scale, geometrically similar, and elastically distorted physical models (figure 1). Time-scaled forcings were generated appropriately, using the UCB earthquake simulator. Three hundred fifty-nine test runs were performed consisting of 277 dynamic and 82 static tests. Several geometrical configurations with one, two, three, and four circular cylindrical models were tested (table 1). Two water depths were used. Both symmetric and nonsymmetric interactions of the structures and water were studied. Pressure distributions on the surface of the models were measured to determine the contributions of normal stress to the total stress acting on structures. During the tests some of the degrees of freedom were partially restricted to yield independent sets of equations for obtaining the added mass coefficients. Data analysis is underway and software has been developed to analyze the data recorded during the tests. Special software has also been developed to correlate different channels of data of any test run to one another, yielding important information about the nature of interactions. The analysis of these tests has been completed, and the Ph.D. thesis on the subject by G. R. Ansari is expected to be completed by 31 December 1982.

After working on the problem of the numerical analysis of earthquake-induced loads on a nonaxisymmetric offshore structure, it was decided to use a finite element method approach, rather than an alternative method, as a way around the high cost was found. A mathematical model was developed, and a computer program was prepared for "rigid" columns. In addition, a mathematical model was developed for flexible columns. The Ph.D. thesis on this phase of the work was completed by Wen-Gen Liao, and has been approved. Some comparisons of theory and results from the tests on the earthquake simulator are given in figure 2. Some of his conclusions follow:

1. An effective numerical procedure to investigate the hydrodynamic interaction between structures submerged in fluid induced by ground motion has been developed.

2. If the structures have uniform cross sections in the vertical direction, this boundary value problem can be reduced to a two-dimensional one. Otherwise, a three-dimensional analysis is required for the nonaxisymmetrical problem. For high frequency ground excitation, the reduced boundary conditions are acceptable. However, a transmitting boundary and free surface condition should be considered for low frequency excitation such as incident waves.

3. The agreement of the results from the experiments of physical model on an earthquake simulator and the numerical analysis has been shown in Example A in Chapter V. However, some minor discrepancies are observed. The discrepancies may be caused by the following reasons: a) the linearization of the boundary value problem in numerical analysis such that the hydrodynamic forces, which are along the center line connecting the centers of the cylinders and are induced by the ground motion perpendicular to this center line, are neglected; b) the square basin being constructed to simulate the unbounded fluid domain such that the boundary conditions of experiments and numerical model are not exactly the same; and c) the uncertainties in laboratory works including the experimental equipment, techniques, and data reduction.

4. The numerical analysis to find the hydrodynamic forces on a nonaxisymmetrical structure can also be applied to an axisymmetrical structure. For solving the structural responses of an axisymmetrical structure, it shows that the results from the theoretical analysis and the numerical analysis are very similar. As the number of wave modes increases, the numerical analysis results approach to the theoretical analysis results asymptotically.

5. When the distance between cylinders is small, the structural responses induced by ground motion decrease in the symmetrical case and increase in the antisymmetrical case. Comparing the structural responses when two cylinders are far from each other so that the interaction is no longer significant, 50% variation for both symmetrical and antisymmetrical cases is illustrated within the examples in Chapter V. Generally speaking, the hydrodynamic interaction is negligible as the relative distance exceeds 4, while it becomes relevant as the relative distance is less than 2. This phenomenon depends on the characteristics of structures, water depth, amplitude and frequency of ground excitation and the relative distance between cylinders.

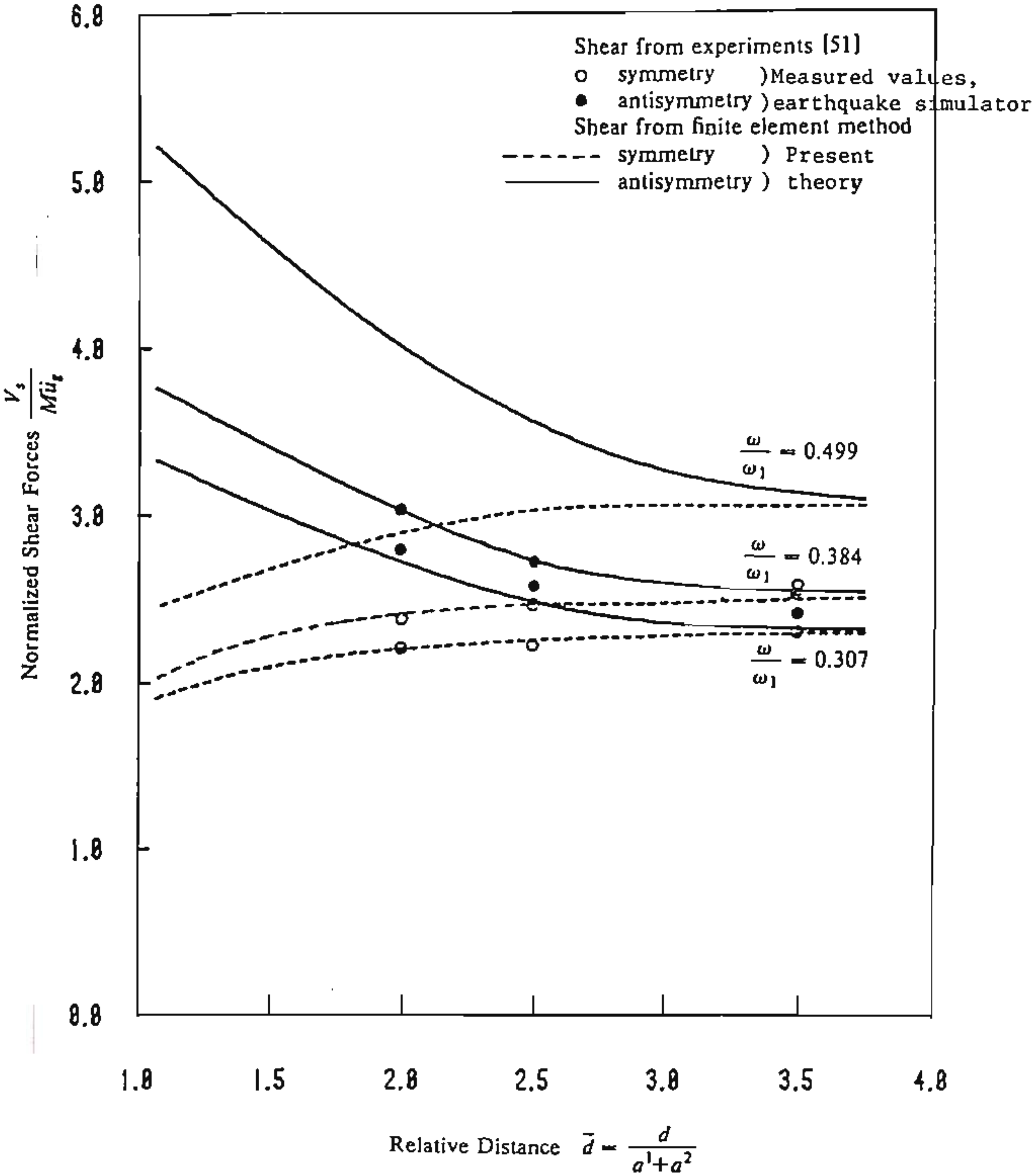
Legend for Figure 1

Model Positions on the Table and Their Coordinates

Cylinder	x cm	y cm
N-0	16.	-17.
N-1	16.	-39.9
N-2	16.	-57.
N-3	16.	-74.2
N-4	16.	-102.7
N-5	16.	-131.4
I-0	16.	-17.
I-1	-6.9	-17.
I-2	-24.	-17.
I-3	-41.2	-17.
I-4	-69.7	-17.
I-5	-98.4	-17.
B-0	16.	-17.
B-1	-0.2	-33.2
B-2	-12.3	-45.3
B-3	-24.4	-57.4
B-4	-44.6	-77.6
B-5	-64.8	-97.8

Note: The coordinates shown above are measured from the center of the earthquake simulator.

Figure 1. The force meter.



Normalized Shear Forces ($\frac{h}{z_c}$=1.782)

Figure 2. Normalized shear forces ($\frac{h}{z_c}$=1.782). Shear from experiments (51): open circles, symmetry, measured values; closed circles, antisymmetry, earthquake simulator. Shear from finite-element method: dotted line, symmetry, present; solid line, antisymmetry, theory.

Cooperating Organizations
State of California

Publications

LIAO, W.-G. September 1981. Hydrodynamic interaction between two cylinders. Report to Ph.D. qualifying examination committee.
LIAO, W.-G. 1982. The behavior of submerged, multiple bodies in earthquakes. Ph.D. thesis, Department of Civil Engineering, University of California, Berkeley. (This is also issued as a technical report of the UCB Earthquake Engineering Research Center and the Hydraulic Engineering Laboratory, as Technical Report No. UCB/EERC-82/16.).

HYDRODYNAMICS OF HARBOR ENTRANCES AND THE MANEUVERABILITY OF SHIPS MOVING THROUGH ENTRANCES

University of California, Berkeley
R/OT-2
1980-81

William C. Webster and Robert L. Wiegel

The research project described below is aimed at investigating two important and interrelated aspects of the navigability of harbor entrances. The first of these topics concerns the generation of currents in the harbor entrance through second-order wave effects. The second treats the effect of these currents on the maneuverability of ships through the entrance. The progress on each of these topics is presented below.

Generation of Currents

Currents at harbor entrances arise from many causes; the principal one is an outflow of some river feeding the harbor basin. Although the existence and characteristics of these currents are reasonably well understood, the observed, significant currents emanating from nonestuarine harbors remains a puzzle. It is this latter situation which we are investigating, particularly the effect of wave action as opposed to effects of tides or harbor resonance. The approach which is adopted is twofold, including a theoretical analysis and scale-model experiments.

Since nonlinear effects are crucial to this study, the mathematical analysis is being conducted using the simplest possible geometry. The geometry selected is a simple, detached breakwater in an otherwise infinite expanse of shallow water of a constant depth. The first and second order velocity potential problems are formulated using Green function methods, and a solution procedure has been developed. Once a solution is obtained, more complicated harbor geometries will be attempted. In both cases mass transport and currents arising from the variation in radiation stresses in the region will be evaluated.

Experimental investigations of the creation of currents in harbor entrances will also take place. To this end the wave basin in O'Brien Hall of the University of California has been selected and modified. The basin bottom has been surveyed in detail (every 15 cm) and has been found to be flat within ± 2 mm. The decrease of surface elevation due to water loss through cracks and evaporation has been stabilized to 3 mm/day. As a result, this will have a negligible effect on experimental runs of the order of 1 hour. The wavemaker mechanism has been modified to provide the capability of changing wave steepness and/or frequency during a run. This is accomplished by placing a remotely controlled actuator on the eccentric driving the paddle.

Effects of Currents on Ship Maneuverability

The maneuvering response of ships in harbor entrances is not well known. Various factors play a role. These include the speed and geometry of the ship, the topography of the channel, and the current distribution in the channel. The research program here is aimed at just one of the complicated interactions, that of maneuvering a ship in a current over an uneven bottom. This situation is a potentially dangerous one since both current and bottom unevenness are not easily observed by the ship's master. Therefore, these represent unknown disturbances to him until he sees their effect. Because ship responses are so slow it may take a minute or two to recover from such a course deviation.

It was the original intent of our study to use the Ship Model Towing Tank at the University of California's Richmond Field Station. An extension to the towing carriage is available which can support a ship model close to the tank bottom. When a small depth of water is used, experiments can be conducted which model the passage of a ship in a shallow water channel. In December 1980 a series of experiments was conducted using this facility in which the current was zero but the bottom was uneven. Measurement of the force on the restrained ship model revealed that the noise arising from the mechanical vibrations in the towing carriage completely masked the forces due to the bottom unevenness. Attempts to filter out this noise did not meet with success since much of the noise was in the same frequency range as forces we were trying to measure. In an attempt to remedy this difficulty, several further attempts were made through the year to conduct meaningful experiments. These attempts included towing the ship model and using a self-propelled model. These tests were not successful because of instabilities of the towed ship trajectories and difficulties in measuring the trajectory of the self-propelled model.

This lack of success prompted us to contact several other test facilities to inquire about their procedures and the difficulties they encountered during similar experiments. This informal survey confirmed that these other facilities also had observed similar problems. In fact, the Maneuvering Basin at the University of Michigan was closed permanently in part because of their difficulty in being able to perform similar experiments.

In light of the poor prognosis for results and because of a change in degree goal of the student trainee from Ph.D. to Master of Engineering, it was decided to have the trainee complete a theoretical project on a distantly related subject of drift forces caused by waves acting on a fixed platform. This project was completed satisfactorily and is currently being written up in the form of a technical paper by the trainee (Mr. Marc Corona). We hope to be able to publish this paper in the next year.

We are currently reevaluating the prospect of conducting further tests in our facility. The difficulties are primarily ones of instrumentation and procedure. If we determine that it does not make sense to pursue this line of attack, we will attempt to develop an analytical approach to the problem.

Cooperating Organizations
State of California

TV/SONAR IMAGING SYSTEM

University of California, San Diego
Scripps Institution of Oceanography
R/OT-3
1980-82

V. C. Anderson

This project has as its objectives the investigation of the effectiveness of a combined display of TV and sonar imaging of underwater objects on the seafloor. There are two phases of the project: to fabricate the sensor and display hardware, and to evaluate the effectiveness of the display in the context of manipulation and observation in an underwater environment.

Fabrication of both the TV interface and the two-dimensional scanning sonar system was completed in the first year of the project. The transducer configuration and drive electronics for the sonar did not operate properly at first. Because of either unbalanced phase drivers or mechanical coupling between the segments of the transducer, or both, the system exhibited unacceptably high sidelobes. The effort in the second year has been devoted to debugging the real-time software programs in both the TV formatting microprocessor and the sonar control microprocessor.

The software is now performing properly and initial composite TV/sonar displays have been generated. The buffer memory system to store the sonar image data has been completed and tested. The mixing method selected is that of multiplying the three color vectors by the black and white TV video signal prior to introduction into the color modulator.

Driver software was completed for both the sonar and the TV modulator system. Two single-board microcomputers (Rockwell AIM-65) were used as controllers. The interface between the sonar and TV systems was implemented through the 8-bit I/O ports of the AIM-65. However, after considerably extended effort at creating a suitable sonar range and sonar amplitude to color hue and color saturation transformation matrix, we have finally concluded that the quantization of our stored color vectors is too coarse to generate a well-graded matrix. Hence, we are in the process of upgrading our 12-bit wide color storage memory to 24 bits wide. This will allow 8-bit color vectors to be used for the sonar data. High-speed multiplying 8-bit digital-to-analog converters will be incorporated in place of the 8-level decoded switches used in the earlier design.

As a result of change in ownership, PaR Systems (now a part of GCA Corporation), is unable to contribute to the loan of a manipulator for use in the project. In lieu of this we have rejuvenated an older, larger manipulator (the model 500) which was used on the Marine Physical Laboratory's remote underwater manipulator RUM II and mounted it on a carriage to operate in the Electrical Engineering and Computer Sciences Department acoustic tank. This will be used in the manipulator tests.

Tests to date have been carried out in a small (3'x4'x2' deep) tank. When the new memory hardware is completed, the tests will be moved to our larger 20' diameter x 5' deep tank where the manipulator is located.

Cooperating Organizations
Hydro Products

DEVELOPMENT OF A METHODOLOGY FOR THE DESIGN, CONSTRUCTION, AND QUALITY ASSURANCE OF THE CORE OF RUBBLE-MOUND BREAKWATERS

University of California, Berkeley
R/OT-5
1981-82

Ben C. Gerwick

This study started in October 1981. The main purpose is to develop a more comprehensive and thorough methodology for the design, construction, and quality assurance of the core of rubble mound breakwaters and its interation with the foundation and the riprap or armor.

Technical reports and data on the state of the art of rubble mound breakwaters with emphasis on the core have been reviewed in depth. Four parts of this study have been accomplished. The first part is a technical investigation about the breakwater foundation. The second part is a study of core materials. The third part deals with construction procedures, and the fourth part is a technical comparison.

The selection of an offshore site is essential for most seafloor engineering projects. So, the first step in breakwater construction is an intensive local condition investigation. Complete and detailed hydrographic, bathymetric, and geotechnical surveys are necessary.

The foundation analysis can be made by means of corings, probings, wash borings, or drillings. It is very difficult to obtain undisturbed samples of surficial cohesionless sediments. If the bottom is very soft or unstable to a significant depth, an excessive amount of rock may be required to reach a satisfactory supporting medium. Settlement, erosion, and liquefaction have occurred at the Crescent City outer breakwater and the Noyo Harbor north jetty near Fort Bragg, California, resulting in a hole or gap under the rigid cap. The foundation failures are classified and studied carefully; special attention should be given in the selection of a good method for the stabilization of the soil.

In some important recent projects, various economical and practicable compaction techniques have been performed to prevent liquefaction. Provision for drainage, so the excess core water pressure can escape, is another possible solution. Several methods for strengthening the foundation soils artificially are discussed in this first part.

In the second part of the study, materials of the core were studied. Different types of rock material were compared and several laboratory tests were performed to determine the criteria and characteristics needed. Investigation of typical quarries was included.

Core materials must be sound, durable, hard, free from laminations or cleavages, and of such character that they will not disintegrate from the action of air or seawater. They must be sturdy enough to withstand both the short-term processes associated with quarrying, transportation, and placing as well as the long-term dynamic processes associated with the life cycle of the breakwater. The rock selected for the protective layers and core material should undergo different tests to determine acceptability. These test results can best be evaluated if accompanied by a service record of this source or type of rock. No tests have been specifically designed for breakwater materials; therefore, applicable tests are selected from ASTM procedures which are used for aggregates for concrete.

The third part deals with the construction procedures. As soon as a contractor has been awarded the project, the design team and the contractor should collaborate to determine if any changes can be made to provide a better structure and to facilitate a more efficient method of construction.

We have completed a technical comparison of design and construction practices between rubble mound breakwaters and other similar aquatic and marine structures such as dams, levees and offshore islands. It includes a detailed review of the criteria and requirements for these structures and an examination of the problems encountered in construction and service. We have, of course, concentrated on the core of these structures and their properties. Several types of equipment are discussed and some examples are provided.

We continue to study surveying and control practices that present special difficulties because of the shallow water, exposure to waves, and the rough nature of the breakwater rock. Various recent developments in electronic and photographic techniques are being investigated for their applicability.

Cooperating Organizations
U.S. Corps of Engineers

University of California, San Diego
R/OT-6
1981-82

DESIGN OF A SEA-FLOOR WORK SYSTEM

V. C. Anderson

The primary tasks accomplished during this first year have been a) the development of a "plan of approach" considering the complete system design concepts, potential problem areas, and logical sequence of development; b) the detailed stress analysis and mechanical design of the manipulator boom; c) the design and fabrication of the seawater servovalves and flowmeters for the control of the manipulator boom; d) the development of the manipulator boom control software; 3) the detailed mechanical design of the thrusters; f) the mechanical design of a 7-inch I.D. electronic pressure case; g) near completion of the electronic design of the power transmission and distribution system; h) near completion of the electronic design of the telemetry system; i) near completion of the electronic design and testing of the vehicle peripheral processor (VPP) and development of its monitor firmware; j) the detailed electronic design and control software for a three-phase controller; and k) the procurement of the shipboard development computer components.

A technical workshop was conducted on October 15, 1981, primarily to gain general design information for RUM III, especially looking for potential problem areas and their possible solutions. Participants in this workshop included Robert Cordy, NCEL; Richard Blidberg and Richard Currier, MSEL/UNH; Fred Spiess, MPL/SIO; James Walton, NOSC; and various MPL personnel who were involved in RUM II and the planning for RUM III. The total system concept and most of the subsystems were discussed. Valuable ideas were gained from Robert Cordy about track systems, seawater hydraulics, and cable dynamics. A cooperative exchange of information about computer hardware and software continues between MPL/SIO and MSEL/UNH.

The design, fabrication, and testing of RUM III is a complex task because of the many subsystems that interface. It requires considerable planning and scheduling to provide orderly and logical initiation and completion of tasks. A detailed milestone chart has been completed to aid in this effort.

The initial design effort has focused on the manipulator boom since it is central to the total system design. This effort was to analyze the forces and stresses occurring in the manipulator boom and thereby determine the specific dimensions of its components. Computer programs have been completed for analysis of the forces on each structural member of the boom for any location of the boom end or any orientation of the three major arms of the boom. A program has also been completed to determine the preferred orientation of the three arms that allows the maximum vertical lifting force for a given end location.

Results of the computer programs have clarified the complex dynamics of a boom that has an extra degree of freedom, determined the useful work area of the manipulator and the maximum force that it can exert in any direction, examined the maximum mechanical stresses in all parts of the boom for the proper selection of materials and optimum design of component parts, and provided the necessary information for the boom control and actuation subsystems for optimal boom movement.

The mechanical design of the boom has been completed and fabrication has begun. A prototype low-pressure seawater hydraulic cylinder made from filament-wound FRP pipe has been successfully tested and the remaining components have been ordered.

Design and fabrication of the seawater hydraulic valve system for the manipulator boom have been completed. This system includes main control valves, pilot valves, flow meters, and two microprocessor systems. The main control valves consist of plastic irrigation valves for control of 100 psi seawater to and from the hydraulic cylinders of the manipulator boom. The throttling of the control valves is done by pilot valves constructed from electrical solenoids modified to act as pinch valves. Flowmeters and a microprocessor along with the valves form a closed servo loop to eliminate the nonlinearities of the system. A second microprocessor will "communicate" with the rest of the RUM III system, receiving desired manipulator boom commands and sending status reports back. This entire system is packaged in an oil-filled, pressure-compensated box that will be mounted on the turret near the manipulator boom.

The concept of the software for the control of the manipulator boom is complete and the beginning program has been written. It is anticipated that the debugging process will continue for at least one year because of the many dynamic variables that can only be determined empirically.

The basic thruster design and testing have been completed in another development project (deep tow thruster pod). The design uses several seawater-lubricated bearings, a helicopter type wobble plate providing dynamically variable blade pitch, and lightweight plastic construction. Test results indicate the design exceeds expected performance goals. Fifty RPM has been chosen as the optimum rotational velocity, giving a thrust-power ratio of 49.6 Kg/HP for a pitch angle of 14.8 degrees. The design for the mounting of the thrusters on the turret and the power drive system will be incorporated in the turret design.

Design of an electronics pressure case has been completed. It uses 7075-T6 aluminum for a cylindrical case and spherical end caps resulting in a minimum weight case and an abundance of space for electrical penetrators.

The design of the power transmission and distribution system is 80% complete. A specialized power transformer has been developed for the deep tow thruster pod that can also be used for the RUM III vehicle power transformer. This transformer is designed to operate at saturation

In the low-load condition, utilizing the resistance of the tether cable as a ballast load. This permits a significant decrease in transformer weight while providing some voltage regulation at the vehicle. Testing of this transformer has been completed with good results.

The directional signal transmission and cable termination schemes have been designed, breadboarded, and tested with good results. The receiver output shows less than 60 db attenuation of transmitted signal without filtering for frequency discrimination.

The design of the telemetry system is 80% complete. Carrier frequencies and bandwidths have been selected. Standard filter design types for all filtering other than hi-pass/lo-pass crossover in line termination networks have been selected. Prototype inductors have been designed for the crossover networks. Detailed electronic design of the telemetry transmitters and receivers is complete. A 20-watt power amplifier for use as a line driver in the vehicle has also been designed and a prototype has been successfully tested.

Development of the vehicle peripheral processor (VPP) is 95% complete. A prototype circuit has been fabricated and tested. Its major components are a 6502 microprocessor, 2K of RAM, 2K of ROM, 4K of either RAM or ROM, 2 dual VIA input-output ports, and an advanced data link controller. A VPP monitor has been developed and tested successfully. Additions to this monitor will be made as the total computer system is implemented.

The 6502 vehicle peripheral microprocessor program that produces the control waveforms for the variable speed 3-phase track drive motors has been completed and debugged.

The shipboard development computer has been procured. It consists of a Q-bus back plane, an LSI 11/23 CPU board, three VT100 terminals, a Cipher magnetic tape drive, a Honeywell 8-inch disk drive, a Microline line printer, a system power supply, and various memory and peripheral control boards. These components have been tested and are being assembled. UNIX will be the operating system.

The shipboard telemetry microprocessor and the vehicle telemetry microprocessor will be 68000 microprocessor systems using converted MPL-ADA monitor and development system software.

Cooperating Organizations
Naval Ocean Systems Center (NOSC)
Fleischmann Foundation
ONR
NCEL
MSEL/UNH

MARINE AFFAIRS

STATISTICAL FORECASTING METHODS FOR FISHERIES MANAGEMENT

University of California, Davis
R/MA-1
1980-82

James Wilen and Richard Howitt

Definition of a Case Study Fishery

This project focuses on developing statistical forecasting models to better aid fisheries managers in making regulatory decisions. The shrimp fishery is particularly interesting because little formal work has been done to analyze the determinants of fishing pressure, particularly the pressure on specific grounds. We have developed models of fishermen's expectations and of optimal search/fishing decisions in order to predict where fishermen will concentrate effort and how effort will shift in response to changes in their decision environments.

The principal problem in defining a suitable fishery for a case study of the stochastic nature of fishing decisions was finding a suitable data set. The ability to detect the strategic reaction that fishermen may have to updated information necessitated continuous time data on fishing location, effort, and catch by boat. In the absence of this detailed information one would be unable to empirically detect whether fishermen were reacting to updated information in the form of recent catch and location data, or whether they were following a pattern of fishing that was not modified by short-run information.

From the outset, we decided that a practical method of incorporating updated information would be on a "decision relevant" basis. Clearly if strategic behavior alters the use fishermen make of the information, the value of providing updated information has to be modified. After extensive interviews and several field trips, the California pink shrimp fishery was selected since it had enough boats (20) in a small area to provide incentives for strategic behavior and a complete data set that covered boat number, trip number, port where the landings were made, Loran A number for both the set and the lift, time of day for set and lift, depth of set, estimate of catch for that set, and the actual landings for the trip. Boat characteristics such as length, beam, net tonnage, horse power, year built, year purchased, and home port were collected. Some additional information on the rig and equipment was collected.

The data had to be hand tabulated from the Department of Fish and Game records and shrimp licenses and then punched, verified, and transferred to computer tape. This data set is being used to estimate statistical models of fishing decisions.

Preliminary Strategy Analysis

Analysis of the data has been ongoing most of the past year. The underlying theory for the equation specification is that fishermen act to maximize their expected profits. At any given time, fishermen's expectations are a stochastic function of the alternative catches and costs of a subset of possible fishing locations. We assume that the expectations are constantly being revised on receipt of additional information on catch and location throughout the season. Clearly the new information is weighed against a set of more permanent expectations or practices based on less rapidly changing variables. The present statistical formulation is a multinominal logit specification.

The logit framework is favored because the expected catch is assumed to be based on lagged values of catch from each area, the relevant information set from which past catches are drawn being based on statistical tests. The fishing area covers approximately 200 miles of coastline ranging from just south of California's northern border to just north of Fort Bragg in 60 to 100 fathoms of water. The fleet is based mainly at Crescent City and Eureka. This suggests the possible grouping of boats with the same home ports into information groups, that is, past catches for boats in a group may come from boats only within that group. Unfortunately, it is certainly not this simple, and other schemes will be formulated.

The final product of this estimation will be a statistically estimated set of probabilities that are functionally related to the included independent variables. This will allow prediction of destination choice by fishermen. It should yield a picture of the organization of information exchanges and some welfare and policy statements, such as an estimate of producer's surplus. It is also possible to invert the resulting probabilities and obtain the expected catch, which would be helpful in management of the fishery.

Cooperating Organizations
California Department of Fish and Game (Statistical Division)
California Sea Grant Marine Advisory Program
Dennis King — private fisheries consultant
National Marine Fisheries Service (Seattle, WA)
National Marine Fisheries Service (La Jolla, CA)
Oregon Department of Fisheries
University of California, Santa Barbara
University of California, Berkeley

Publications
EALES, J. AND WILEN, J. 1982. An empirical example of searching behavior in the pink shrimp fishery. Presented at the Society for Industrial and Applied Mathematics (S.I.A.M.) Conference, Stanford University, August 1982.

MANAGEMENT OF MULTISPECIES SYSTEMS: THE PACIFIC HAKE EXAMPLE

University of California, San Diego
Scripps Institution of Oceanography
R/MA-2
1980-82

Daniel Goodman and Payson Stevens

Two landmark pieces of legislation, the Fishery Conservation and Management Act of 1972 (FCMA) and the Marine Mammal Protection Act of 1976 (MMPA), explicitly set ecosystem level criteria under which biological resources of the sea should be managed. These substitute for the traditional goal of maximum sustainable yield (MSY), based on single species concepts, a goal of population management that takes into account the effects of other species on the target population and the effects of the target population on other species in the system. Management of a multispecies system will be investigated using the Pacific hake example.

Pacific hake, *Merluccius productus*, are found off the coasts of Washington, Oregon, and California in numbers that could support a much larger harvest than is currently taken. The hake is not very desirable as a food item in the United States, so the market for it is weak and the U.S. fishery is underdeveloped. Foreign fleets, especially Russian, have at times taken a substantial hake catch inside the U.S. 200-mile limit (Bailey *et al.*, in press). The history of the catch per unit effort of hake by the USSR and Poland in U.S. waters indicates that stock size of hake, over a 14-year period, was not affected by these foreign harvests.

Many policy questions arise with regard to the merits of encouraging development of a U.S. fishery for hake, and appropriate policy for regulating the foreign catch. Underlying these are fundamental biological questions regarding the consequences for the ecosystem of harvesting a species which stands in the relation of competitor, predator, and prey to various other species involved in important fisheries. The complexity of these biological questions is well known. The complexity of the policy considerations bearing on regulation of the foreign catch is illustrated by the fact that recent political events having no direct connections to fisheries led to a decision to close U.S. waters to the Russian fleet, with the consequence that the Russian fishery is now conducted via a formal institution of joint ventures.

In practice, it has proven difficult to specify mathematically how the new multispecies management program should be formulated. Furthermore, there is serious concern whether the data requirements for the application of the criteria set in the Fishery Conservation and Management Act and Marine Mammal Protection Act to actual fisheries can be met.

We intend to investigate both the theoretical and practical problems by carrying out an analysis of multispecies considerations bearing on the management policy for the Pacific hake fishery.

The overall project objective is to produce a multispecies model that will focus on the ecological and social consequences of management decisions regarding the Pacific hake fishery. The interactions that will receive most careful examination are hake predation on pink shrimp, marine mammal predation on hake and shrimp, and incidental catch of other related species during the course of hake fishing. The model and its analyses will then serve as a test case for application of multispecies management criteria, and these will be examined in light of our experience with the hake model. The first year of this study was devoted primarily to accumulation of background material concerning the basic biology of the hake, the economics of the hake fishery, and likely important interactions of hake with other species.

We have concluded our review of the natural history of the Pacific hake, and have produced a monograph on that topic and contributed to a review coauthored with two National Marine Fisheries Service (NMFS) scientists. This accumulation of background information began with a compendium of data on abundance and distribution. The natural history and annual migration pattern of the hake is shown in figure 1. Seasonal abundance patterns of the larvae indicate that between 1963 and 1979, the greatest number of hake larvae were found between January and February (Bailey *et al.*, in press). The geographic distribution of reproduction indicates that along the California coast, from San Francisco to San Diego and from central to southern Baja California, large numbers of Pacific hake eggs and larvae are found in January. A history of larval abundance, by Stauffer and Smith (1977), shows that spawning stock of hake decreased in the late 1960s to early 1970s compared to earlier years, and recently has increased to pre-1960 levels (Bailey *et al.*, in press). Bailey *et al.* (in press, data from Alton, 1972) in their study on the depth distribution of hake with respect to season, showed that there was a decrease in the average depth of catches in bottom trawls in the early summer and an increase in the fall. In the temperature-salinity structure of waters where hake have been found abundant, spawning appears to commence when adults migrating south arrive in warm, saline southern waters (Bailey *et al.*, in press).

Major biological interactions are schematized most conveniently in a food web. Figure 2 represents a simple food web for the hake, and includes those interactions which are probably the most important. Our current efforts are devoted mainly to attempts to attach specific numbers to the stock sizes and rate coefficients which are important quantities and linkages in that web. To date, we have had best success in locating data relative to the hake's role as a significant predator in the coastal system. Information on prey composition (data from Gotshall, 1969; Outram and Haegle, 1972; and Alton and Nelson, 1970) show that the rate of hake predation on euphasiids is a function of hake body size (i.e., larger hake eat more fish and less euphasiids). Seasonal variation in relative frequency of the hake's food items show that crustaceans, which are the hake's major food source in the spring and summer, decline in frequency as a prey item in the winter. In winter, fish become the dominant food source. The diurnal migrations of the hake have been compared to the migration of their primary prey, euphasiids, as a possible adaptive mechanism (Alton and Nelson, 1970). The question of biological interactions was motivated by the thought that if the hake is an important competitor of (or predator on) some species which is the basis of a U.S. fishery, then it might be desirable to encourage a higher hake catch for the indirect benefit which would accrue through the reduction in that competition or predation pressure. A prime candidate for such an interaction is the predation of hake on pink shrimp.

Important pink shrimp fishing grounds overlap the range of the hake population (Stevens, submitted). Data on occurrence of pink shrimp in the diet of the hake have been shown by Stevens (submitted). The relative shrimp consumption by different size classes of hake indicate that the larger hake appear to consistently eat more shrimp than smaller hake. The presently available quantitative information can be utilized to compute the actual impact of total hake predation on the stock of pink shrimp (Stevens, submitted; Ehrich *et al.*, 1980). These calculations indicate that the impact could be very substantial. The histories of hake and pink shrimp landings show an increase in shrimp catch concurrent with increases in the hake catch (Bailey *et al.*, in press), suggesting that the hake fishery might indeed improve conditions for the shrimp. However, when this information is reexpressed as catch per unit effort, which ought to be a better indicator of the respective abundances, this relationship is not apparent (Stevens, submitted).

We are now occupied in attempts to refine the estimates of those parameters which contribute most to the present range of uncertainty regarding our assessment of the possible role of hake in depressing pink shrimp populations. Incidentally, we thought there might also be a biological question concerning the role of hake as an important food item in the diet of other organisms.

Data on the consumption of hake eggs and larvae by likely predators indicate more predation on yolk sac larvae than on eggs but consumption of both could be substantial. These larvae seem vulnerable to invertebrates such as some species of amphipods, crab larvae, copepods, and medusae. We believe that there might also be an important biological and management question concerning the role of hake as a major food item in the diet of some marine mammals, notably sea lions, in which case there might then be reason to discourage harvest of the hake, in order to maintain the mammal population (though it might be argued that marine mammals compete with us for fish). This interaction will be pursued in the current year's investigations.

One additional interaction that is more a function of the fishery process than of strictly biological interaction, is the involvement of incidental catches, such as sable, in the hake harvest. Since these can have important policy implications, resulting in the closing of this and other fisheries when some limit is exceeded, these too are being investigated.

Our efforts during the first year were based on literature searches and personal interviews. To this end, the trainee on this project, Payson R. Stevens, has traveled to Seattle, Portland, and Santa Cruz to use the libraries at NMFS and University of Washington, and the files at NMFS and the Pacific Fishery Fishery Management Council, and to discuss matters with scientists at these institutions and with representatives of the fishing industry.

Finally, in order to convert information on stocks to information on rates, we have considered available life table data for the hake. These include the vital rates deduced in part from data on age distribution (Bailey and Ainley, in review; and Bailey *et al.*, in press), the calculated mortality rates based on fertility and survival (Bailey *et al.*, in press), the growth rates of hake as a function of age or size (Bailey *et al.*, in press; and Bailey and Ainley, in review), and the fitted Bertalanffy growth equation (Bailey *et al.*, in press).

The primary 1981-82 objectives have been to construct a working computer model of the Pacific hake system based on relevant stock and rate processes. Specific objectives include 1) reviewing mathematical theory of multispecies fisheries, 2) incorporating into the model additional information on the interaction of incidental catches in the hake harvest, 3) evaluating the consequences of possible policy options based on the model, and 4) exploring the predictive capacities of present uncertainties in the data.

Preliminary ecological modeling has been approached through compilation of information for energy budgets of hake feeding and growth, and for relating these quantities to the potential impact of hake feeding on the stock of pink shrimp. Theoretical modeling has been pursued via analysis of the nature of regulatory feedback in a variety of one-, two-, and three-species model systems. In the final year of the project, these models will be analyzed in greater detail with regard to the consequences of different sorts of regulatory feedback under harvest.

The work of the past year and a half has resulted in the production of two major papers presented at workshops (the November 1981 First Western Groundfish Conference at Glendon Beach, Oregon, and the January 1982 U.S.-Canadian Technical Subcommittee Pacific Whiting Workshop). The first of these papers (CalCOFI Reports, October 1982) deals mainly with background biological information. The second paper emphasizes policy options bearing on development of the fishery and describes the institutional framework within which these decisions must be made. Key features of the discussion are an analysis of the present role of joint ventures in the fishery, and an assessment of the possible interaction between the hake and pink shrimp fishery (which appeared as a technical report to U.S.-Canadian Subcommittee on Pacific Whiting).

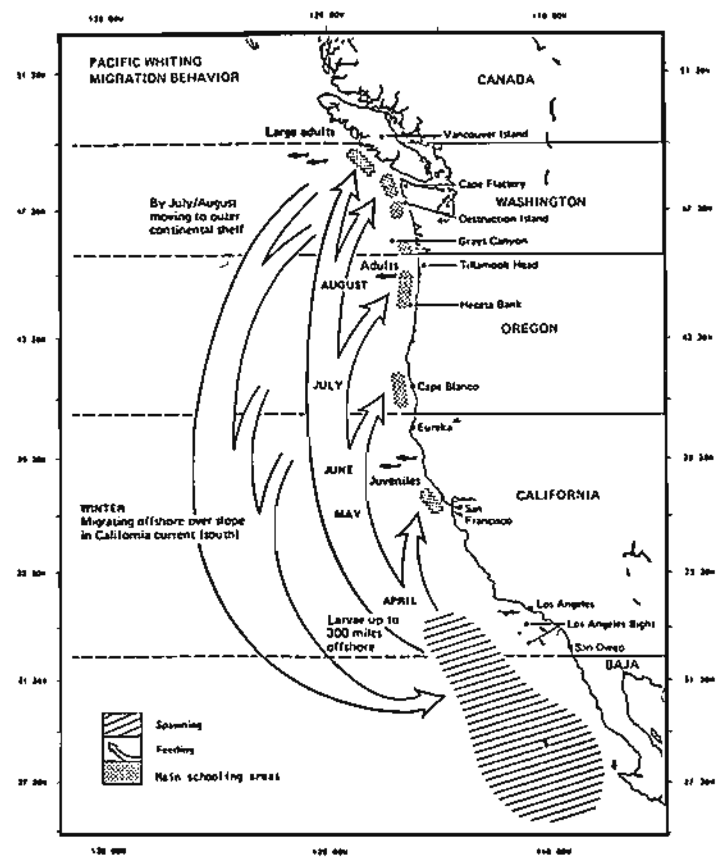


Figure 1. Migratory patterns of Pacific whiting.

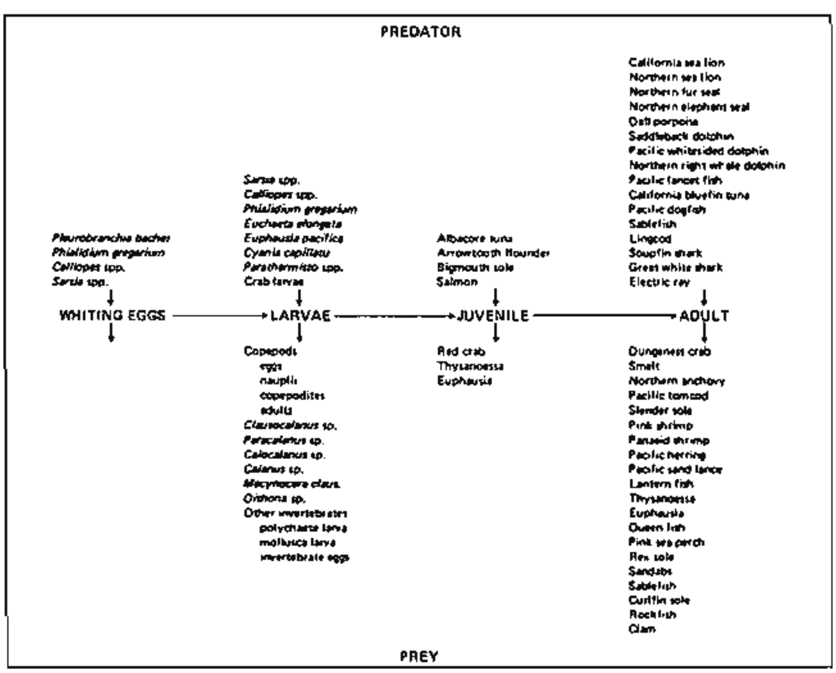


Figure 2. Food chain: Pacific whiting, *Merluccius productus*.

Cooperating Organizations
National Marine Fisheries Service
Oregon Department of Fish and Wildlife
Pacific Fishery Management Council

References

ALTON, M. S. AND NELSON, M. O. 1970. Food of the Pacific hake, *Merluccius productus*, in Washington and northern Oregon coastal waters. USFW Circ. 332:35-42.

BAILEY, K. M. AND AINLEY, P. The dynamics of the California sea lion predation on Pacific hake. (In review).

BAILEY, K. M., FRANCIS, R. C., AND STEVENS, P. R. 1982. The life history and fishery of Pacific whiting, *Merluccius productus*. Processed Report 82-03. Northwest and Alaska Fisheries Center, NMFS. (Under review).

EHRICH, S., MOMBECK, F., AND SPEISER, G. 1980. Investigations of Pacific hake stock in the NE Pacific. Arch. Fisch. Wiss. 30(1)L:17-38.

GOTSHALL, D. W. 1969. Stomach contents of Pacific hake and arrowtooth flounder from northern California. Cal. Fish. Game 55:75-82.

OUTRAM, D. N. AND HAEGLE, C. 1972. Food of Pacific hake, *Merluccius productus*, on an offshore bank southwest of Vancouver Island, British Columbia. J. Fish. Res. Bd. Can. 29:1792-1795.

STAUFFER, G. D. AND SMITH, P. E. 1977. Indices of Pacific hake from 1951-1976. Admin. Rept. No. LJ-77. Southwest Fisheries Center.

STEVENS, P. R. Submitted. Pacific whiting: a multispecies management problem.

Publications

BAILEY, K. M., FRANCIS, R. C., AND STEVENS, P. R. 1982. In *The life history and fishery of Pacific whiting,* Merluccius productus, J. Olfe and M. L. Cook, eds. CalCOFI Report. Volume 23.

BAILEY, K. M., FRANCIS, R. C., AND STEVENS, P. R. 1982. The life history and fishery of Pacific whiting, *Merluccius productus*. Processed Report 82-03. Northwest and Alaska Fisheries Center, NMFS. (Under review).

STEVENS, P. R. In press. 1981. A literature review of the natural history of Pacific whiting. NMFS Report.

STEVENS, P. R. Submitted. Pacific whiting: a multispecies management problem.

IMPROVED PROCEDURES FOR SALMON MANAGEMENT IN CALIFORNIA: BIOECONOMIC APPROACHES

University of California, Davis
R/MA-3
1980-81

James E. Wilen and Louis W. Botsford

With limited time and funding, we confined our efforts to two specific issues: the cycles in abundance of salmon catch and estimation of factors influencing effort in the sport fishery. We also collected data and background material for further work on predicting salmon abundance.

We first showed that cycles in salmon catch were significant and just as strong as cycles in crab catch (Botsford *et al.*, Submitted). We then showed that the cycles were not as strong in silver salmon as in king salmon, but this result is tempered by the paucity of silver salmon data. The cycles were present in central California before the decline of the crab population but were not as strong following the decline. Since salmon and crab fishing seasons overlap, decreased northern California salmon catch in years of high northern California crab catch could have been caused by decreased effort in the salmon fishery because of fishermen continuing to fish crab rather than switching to salmon. We showed that this was not the case. Thus, the cause of cycles in salmon catch is still unknown.

The economic segment of this study was impacted by a 3-month delay in obtaining environmental data. While some of the aggregate catch, effort, and meteorological data has been analyzed for possible interrelationships, much better results are expected from recent data at shorter time scales.

In addition to the above concrete results, we have also gathered information on available California data and related work conducted by the California Department of Fish and Game, on significant factors identified as affecting salmon abundance in Oregon and Washington, and on methods used to predict salmon abundance in Alaska.

Cooperating Organizations
California Department of Fish and Game
National Climate Center
Pacific Environmental Group, National Marine Fisheries Service
Salmon Plan Development Team, Pacific Fishery Management Council

References

Botsford, L. W., Methot, R. D., and Wilen, J. E. Submitted. Cyclic covariation in the California king salmon (*Oncorhynchus tsawytscha*), silver salmon (*O. kisutch*) and dungeness crab (*Cancer magister*) fisheries. U.S. Fish. Bull.

Publications

Botsford, L. W., Methot, R. D., and Wilen, J. E. Submitted. Cyclic covariation in the California king salmon (*Oncorhynchus tsawytscha*), silver salmon (*O. kisutch*) and dungeness crab (*Cancer magister*) fisheries. U.S. Fish. Bull.

ANALYSIS OF INDUSTRIAL ORGANIZATION OF COMMERCIAL PACIFIC MARINE FISHERY MARKETS

University of California, Davis
R/MA-4
1980-82

Leon Garoyan

Data for the analysis of specified marine species were obtained from the Pacific Coast Fisheries data base for the years 1974-76 from respective fish regulatory agencies in California and Washington, and for the year 1976 in Oregon. In 1982 this data base was supplemented with data for 1978-80 for California, Oregon, and Washington. Additional information was obtained this year on dealer (buyer) concentration for each selected species for each port in order to complete the process of data-base preparation. Many technical problems have been encountered with the Washington data, requiring large expenditures of time and money for preparing the data for analysis. Also, Oregon has been unable to provide buyer concentration data, precluding the use of one variable deemed significant by the project leader.

Analysis of variance has indicated prices paid to fishermen for identical species, during identical weeks, vary in like ports (ports having similar fishing fleets, market, and transportation conditions). Two econometric models were developed and tested to help explain such price variations, using cross-sectional time series data. A price differential model was selected over a seemingly unrelated model, largely because of the nature of the available data. In addition, the selected model enables a more precise test of significant price differences than did the earlier ANOVA.

The price differential model has been tested with ground fish purchases during each year (1974-76) in the port groupings shown in table 1.

Regression analyses utilizing the price differential model applied to Dover sole, Rex sole, and sablefish prices in those ports where the price differential was statistically significant yielded the conclusion that the market supply (quantity) of these species was the significant variable explaining price differences between ports. In the application to price differences for sablefish, buyer concentration was a significant variable in some port groups.

Results of the regressions will be used during interviews in appropriate ports to determine institutional explanations for other price variations not accounted for statistically.

Table 1

California: Availability of Data for Testing Specified Bottom Fish, 1974-76

	Dover Sole	Rex Sole	Sablefish
Port Group 1			
Crescent City	Y	Y	Y
Fort Bragg	Y	Y	Y
Eureka	Y	Y	Y
Port Group 2			
Bodega Bay	Y	Y	Y
San Francisco	Y	Y	Y
Sausalito	N	N	N
Port Group 3			
Moss Landing	Y	Y	Y
Monterey	Y	Y	Y
Port Group 4			
Morro Bay	Y	Y	Y
Santa Barbara	Y	Y	Y
Port Hueneme	N	N	N

Y = Data available for testing all variables through regression analysis.

N = Significant data gaps preclude testing of the model.

Cooperating Organizations
California Department of Fish and Game
California Sea Grant Marine Advisory Program
National Marine Fisheries Service
Oregon Department of Fish and Game
Washington Department of Fisheries

A STUDY OF DIRECT AND INDIRECT ECONOMIC LINKAGES ASSOCIATED WITH THE CALIFORNIA SEAFOOD INDUSTRY AND AN ANALYSIS OF THEIR IMPACTS ON THE EMPLOYMENT, INCOME, AND LEVEL OF ECONOMIC ACTIVITY IN CALIFORNIA

San Diego State University
R/MA-5
1980-81

Dennis M. King

The overall goal of the project was to construct an input-output model of California fisheries and seafood industries. The model must describe how California fisheries are linked with the rest of the California economy and be capable of generating economic multipliers to show how biological, economic, and regulatory changes related to fisheries throughout California.

The fish harvesting and processing industries in California were aggregated into industrial sectors (19 harvesters and processors), and a 400-sector input-output model of the 1977 California economy was collapsed to 30 sectors and updated to 1980. Economic information for fish harvesters and processors was collected from secondary data, mail surveys, face-to-face interviews, and data review sessions with industry and government leaders.

The research resulted in three tables that are useful for evaluating the economic impact of fisheries. First, the fish production matrix shows the dollar value of each of 14 species of fish landed by each of 19 California fleets. Second, a fish-processing matrix shows the value of fish purchases of each of the 14 species by each of 9 fish-processing sectors. Third, and most useful, the Leontieff-type input-output model shows the dollar transactions that link the 19 harvesting sectors and 9 processing sectors with each other and the 30 nonfishery sectors of the California input-output model. The model also shows fishery-related purchases and sales from outside California and transactions with California households through the payment of wages, rents, and interest, and the selling of fishery products.

The analysis of the data through the input-output model also results in economic multipliers which are useful for government and industry decision-makers. Each dollar of sales by each sector generates sales, income, and taxes in other related industrial sectors estimated through the model. The impact of changes that affect one or more fish harvesting or processing sectors can likewise be estimated by applying multipliers to projected direct changes in sales by each sector.

The model describes the 1980 California economy and needs to be adjusted when conditions change significantly from those that existed during 1980. However, the technical relationships described in the model and the general magnitude of the multipliers will remain useful for several years and provide a foundation for updated or extended models.

Cooperating Organizations
California Department of Fish and Game
California Seafood Institute
Center for Marine Studies, San Diego State University
National Marine Fisheries Service
Pacific Coast Federation of Fishermen's Organizations
U.S. Coast Guard

TECHNOLOGICAL CHANGE IN THE SALMON CANNING INDUSTRY: BLAINE, WASHINGTON, 1890-1930

University of California, Berkeley
University of California, San Diego
R/MA-6
1980-81

Harry N. Scheiber

The investigation's main purpose is to study patterns of technological change in the canning industry and interrelationships between such change on the one hand and public policy, business strategy, labor, and marketing on the other. Initially the focus was on a single cannery, at Blaine, and on the San Francisco-based Alaska Packers' Association. In his research, trainee Patrick O'Bannon investigated a wide variety of data sources — including government documents, company records, trade journals, newspapers, and private letters — making it feasible to expand the scope of the study to encompass the entire Pacific Coast salmon canning industry in the 1890-1930 period. Significant differences in innovation patterns between major fisheries regions have been identified, and these differences apparently were as significant as common patterns that have been identified.

Research — conducted in libraries and archives in all three Pacific Coast states and in British Columbia — has yielded much data on wages, labor force, production techniques and costs, marketing, and profits. When completed, O'Bannon's dissertation will offer not only an analysis of technological innovation and historic development of a major fisheries industry but also a repository of systematized quantitative data on important aspects of the history previously given little attention by scholars. Research to date has revealed that the canneries owned by the Alaska Packers Association in Alaska continually exhibited a higher degree of mechanization than canneries located elsewhere. The study will identify specific linkages — to fishery yields, labor supply, market changes — that explain differential regional patterns of innovation in the industry; it will also cast light on economies of scale in relation to historic technological innovation.

Thus, the dissertation, now nearly completed, will provide a regional history of an important Pacific Coast industry. The initial goals of the study — to reveal patterns of change in the Blaine operation — have been broadened to embrace collection of data on the entire Pacific Coast region; but the methodology remains essentially that of the history of technology and of business and economic history.

O'Bannon presented a portion of his work to an audience of scholars, government personnel, and industry representatives at a conference on agricultural marketing, sponsored by the Agricultural History Society, at the University of California, Davis in June 1981; the paper will appear shortly in the society's journal, *Agricultural History*. The dissertation should be completed and submitted to the UC San Diego department of history during the late winter of the current, 1981-82, academic year.

Cooperating Organizations

Alaska Packers Association, a division of Del Monte
Alaska State Historical Library
Bancroft Library of the University of California at Berkeley
Center for Pacific Northwest Studies at Western Washington University
Oregon Historical Society
University of British Columbia
University of Washington

Publications

O'Bannon, P. In press. 1982. Technological change in the Pacific coast canned salmon industry, 1900-1925: a case study. In *Agricultural history*.

A HISTORY OF THE COMMERCIAL FISHERMEN OF MONTEREY BAY—THE ROLE OF PUBLIC POLICY

University of California, Santa Barbara
R/MA-7
1981-82

W. Elliott Brownlee

During 1980-81 the trainee identified, collected, and partially interpreted data relating to the history of the Monterey Bay fishery. The emphasis was on how public policy decisions have affected the fishing community. After collecting documents, reports, newspaper articles, etc., a decision was made to concentrate first on the relationship of the fishing community with public policy agencies at all levels of government. The result of this approach is entitled, "Commercial Fishermen and the Process of Vertical Mobility: A Working Paper."

The paper demonstrates the historical relationship of fishing communities within the larger community — both local and national. This approach recognizes that commercial fishermen have been mainly southern Europeans who faced the hardships of belonging to an ethnic minority group that was Catholic and whose native tongue was not English. Furthermore, as fishing was and is conceptually nonindustrial, fishermen had little prospect of upward social mobility in the U.S. industrial setting from the late nineteenth century to the present.

During 1981-82 the trainee was engaged in the interpretation of data collected over the previous year. He concentrated mainly on material collected from state and federal agencies relating to the sardine industry from 1900 to 1949 in Monterey Bay. Basically the data indicates that there was a reluctance on the part of the California State Legislature to delegate any meaningful authority to the state's fish and game authorities to enable them to regulate the state's largest fishery.

The demise of the sardine fishing population was not something that was unexpected when it occurred in the late 1940s. From 1919, at the beginning of the large-scale commercial sardine fishery, various state fish and game researchers warned of the impending disaster in the commercial sardine fishery.

Only once, in 1929, was there a strong movement — supported by fishermen, processors, and state agencies — to control the yearly catch. Unfortunately, offshore reduction plants, working outside of the state's jurisdiction, became the scapegoat for the regulation of the industry. Reduction interests, based on shore, complained that they would be unable to compete economically with the offshore reduction plants if they were forced to adopt a yearly quota. This and the worsening economic depression of the 1930s put a halt to imposing a yearly catch limit on the sardine.

However necessary this may have been during the heyday of the "floaters," once they disappeared in the mid-1930s the shore-based reduction interests used other arguments to put off any serious action toward establishing a yearly catch limit for sardines. At first the reduction interests used the depression as an argument against the enactment of a catch limit; unemployment, then as now, is a strong political weapon. In addition, due to the heavy profits on the resulting meal and oil, more and more reduction facilities were installed in canning plants. These investments plus the threat of idle workers resulted in yearly catches of 500,000 to 700,000 tons of sardines, a far cry from the 250,000 to 300,000 tons recommended by fishery scientists.

The California commercial sardine fishery was able to come to prominence because of World War I. Canneries in Monterey were built one after another to supply both export and domestic demands for a meat substitute from 1915 to 1918. With the advent of another war in 1939, the canning part of the sardine industry, which was on the decline in the 1930s, received a shot in the arm as it was revitalized, first for export trade with the allies, then for domestic usage. The wartime need further stalled any thought of a yearly catch limit on sardines.

With the end of the war came the end of the sardine industry. From 1946 to 1949 the catch was very sporadic, forcing Monterey's fishing fleet to go farther south each season until there was little reason for Monterey's canneries to remain open. One by one, the plants along Monterey's famed Cannery Row closed. One plant, built at the end of the war in anticipation of continued prosperity, was never opened; its equipment was finally sold to a Peruvian company in the early 1950s.

There are two main scientific arguments for the demise of the sardine fishery. One group of scientists, from the U.S. Department of Fish and Wildlife, argued that changing environmental conditions forced the sardine spawning population into other waters and this led to a decline of adult fish. Another group, represented by the California Fish and Game Department scientists, argued that the decline was simply due to overfishing, an argument they first proposed in the infancy of the industry. Regardless of which argument is correct, or if the truth lies in a combination of the two, this is not really the whole issue in the sardine matter. What lies at the heart of the sardine failure, in the 1940s (or at a future date), we believe, was the reluctance of the California State Legislature to allow its own scientists and regulatory agencies to have a meaningful say in the future of the fishery. Instead, it seems the legislature took the politically expedient way out and nothing was done.

THE ROLE OF INDIVIDUAL PERCEPTION AND STRUCTURAL POSITION IN THE DEVELOPMENT OF FISHERY MANAGEMENT POLICY

University of California, Santa Cruz/ University of California, Santa Barbara R/MA-8 1980-81

Michael K. Orbach and Biliana Cicin-Sain

This 1-year project had three major goals: 1) to trace and define the set of actors and issues involved in the development of the northern anchovy Fishery Management Plan approved by the Secretary of Commerce in 1978; 2) to reconstruct the course of policy formulation as the Fishery Management Plan progressed through the development and implementation process; and 3) to map, through in-depth interviews with all of those in the policy network, the differing perceptions and representations of policy issues and their implications for the policy process.

Beginning in November 1980, a series of preliminary interviews were performed with individuals known to have played key roles in the anchovy Fishery Management Plan (FMP). Using an iterative key informant approach, a network of individuals was identified which ran from the fishermen and their representatives in southern California at one end to persons in the Office of the Administrator of the National Oceanic and Atmospheric Administration (NOAA) at the other. Using a variety of boundary test procedures, this network was validated and used as the universe of interviewees.

To reconstruct the course of policy formation as clearly as possible prior to the interviews with network participants, several sources of information were collected and analyzed. Minutes of the Pacific Fishery Management Council meetings from the council's inception in 1976 to the present were searched for references to material or discussions related to the anchovy FMP and for general information concerning the nature of the FMP process in the 1977-78 period during which the anchovy FMP was being developed. The National Marine Fisheries Service's ARIS file was searched for all material related to the anchovy FMP, and the relevant data collected and summarized. All drafts of the FMP itself were assembled, and the changes from draft to draft noted and keyed to council, NMFS, and other activities occurring concurrent with the production of each draft. All available technical and popular reports and articles concerning the anchovy fishery in general, and specifically the way in which the various scientific parameters were taken into account in the development of the management options, were collected and analyzed.

Beginning in March 1981, interviews were conducted with all of the individuals identified in the task cited above. All 30 of the individuals, who were widely dispersed in California, Oregon, and the Washington, D.C. area, expressed interest in and agreed to be interviewed, and a 100% sample of the network was obtained. The interviews averaged approximately 2 hours each, and some individuals were contacted one or more times after the initial interview for further information or clarification. The interviews were administered from a common interview instrument and addressed the FMP process, policy issues, the informant's role in the process, the roles of other individuals, agencies, and institutions, the role of flexibility and personnel turnover, the impact of the Fisheries Conservation and Management Act on anchovy management, and the informant's evaluation of outcomes. Information from these interviews is presently being coded and analyzed.

Preliminary analysis of our data indicates that all three of the original hypotheses set out in the research proposal were validated and accepted.

Hypothesis One. For a given FMP, there exists a specific network of individuals ranging from fishery constituents to persons in the Office of the Secretary of Commerce whose activities and decisions play primary roles in policy development and implementation for that FMP. Further, these individuals may not be the "normative" decision-makers but staff personnel, attorneys, or even individuals outside of the agencies or councils themselves. The network we identified for the Northern Anchovy FMP numbered approximately 30 people, relatively evenly distributed among the numerous organizations involved with the anchovy fishery or fishery management, but who as a group constituted an interconnected and definable network that was relatively constant over time, and whose behaviors and perceptions were regular and recordable.

Hypothesis Two. The different structural positions, backgrounds, and information resources of the individuals in this network result in significantly different perceptions of policy questions and issues with respect to a given FMP. A case in point is the question of the U.S.-Mexico relationship with respect to anchovy management. At the local and regional levels of the network, this question was raised as a major policy issue. At the national levels, however, this was often not even raised as an issue. This was a somewhat unexpected finding, the apparent cause of which is the perceived lack of any appropriate context within which to effectively deal with such an issue on the part of senior NMFS and NOAA personnel.

A second example is the problem of "multiple hats" worn by key individuals at the regional level of the network. Many of these individuals, because of their particular backgrounds or expertise, found themselves having to adjust their participation in the process to fit the particular context in which they were expected to perform at a given time, contexts which were switched frequently. Thus a member of the Plan Development Team who was also an employee of the California Department of Fish and Game had to "switch hats" depending upon whether he was performing a given function for the California Fish and Game Commission or the Scientific and Statistical Committee of the Council. This created considerable role stress for these individuals.

Many such examples were collected from the interviews to validate this hypothesis.

Hypothesis Three. The structural and perceptual differences that exist within the network create potential and actual impediments to uniform and coherent policy development and implementation. Some of the same examples cited previously address this hypothesis also. The preoccupation of many of the regional network participants with the Mexican issue, an issue which was not even considered a realistic portion of this particular FMP process when the original FMP was being developed by others in the process, led to some degree of inefficiency of effort in the development of the FMP by siphoning off effort that could have been more usefully directed at an outlet with more potential for effective action.

As another example, the general assumption at the regional level was that the innovative optimum yield "formula" contained in the anchovy FMP was a less-than-welcome perturbation in the process at the Washington, D.C. review level. This turned out to be in fact quite untrue, in that the NMFS (Washington office) personnel in particular, after some initial procedural and legal questions, welcomed the formula approach as an integral part of a new process they themselves had been attempting to develop for some time. A third example is the very uneven distribution of knowledge and awareness of the facts concerning ability and inclination of the Department of Fish and Game and the National Marine Fisheries Service to actually regulate the fishery, an ability which historically has lain — and even with the FMP in place continues to lay — with the state.

In addressing these three hypotheses, this project has uncovered a series of interesting and in some cases unexpected properties of the policy development and implementation process as it was constituted in the case of the northern anchovy FMP. Many of the findings are also generalizable to the policy process in general, and further analysis of the data in the next few months will elaborate on these findings.

Cooperating Organizations
California Department of Fish and Game
California Fish and Game Commission
Department of State
Fisheries Management Division of the National Marine Fisheries Service
Living Marine Resources Inc.
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
Office of Resource Conservation and Management
Pacific Fishery Management Council

MARINE MAMMALS/FISHERIES CONFLICTS: EMPHASIS ON SEA OTTER/SHELLFISH FISHERIES CONFLICTS IN CALIFORNIA

University of California, Santa Barbara
R/MA-9
1980-81

Biliana Cicin-Sain

This project was concerned with analyzing conflicts between marine mammals and fisheries at two levels: at the national level, through study of the congressional passage and national implementation of the Marine Mammal Protection Act, the Endangered Species Act, and of related fisheries legislation; and at the regional level, through intensive study of the sea otter/shellfish fisheries controversy in California, with particular emphasis on the administrative and political history of the issue, and on analysis of the management options. Because of the complexity and controversial nature of the sea otter issue in California, most of our efforts during the past year focused on the regional issue. Hence, accomplishments on the regional study are discussed first.

Four major tasks were accomplished in the regional part of the study: 1) a detailed administrative history of the sea otter/shellfish fisheries issue was compiled, 2) the complexity of the current management framework was reviewed and explained, 3) the available management options were analyzed in terms of a set of very explicit evaluative criteria, and 4) the results of the study were disseminated in a large scale regional forum on the issue, which I cosponsored in January 1981.

Results of research tasks 1–3 are summarized in the paper "Sea Otters and Shellfish Fisheries in California: Management Framework and Options" (forthcoming in B. Cicin-Sain, P. Grifman, and J. Richards, eds., *Interdisciplinary Perspectives on Marine Mammal/Fisheries Interactions*). Research on this paper entailed analysis of extensive internal agency memoranda and other records which the California Department of Fish and Game kindly made available to me; analysis of materials from other state and federal agencies, most prominently the U.S. Fish and Wildlife Service; analysis of a wide range of secondary sources; and personal interviews with key actors (both from the public and private sectors) who are currently involved (or who had historically been involved) with the sea otter/shellfish fisheries controversy. The paper presents, first, a detailed administrative history of the relationship among sea otters, shellfish fisheries, and humans since the early part of the century (when the sea otters were discovered along the Big Sur coast in California) to the present. Analysis of the administrative record reveals a history of long-standing controversy whereby similar issues have been debated for at least the past 25 years without much progress toward resolution.

Management positions have changed markedly little over this long time span, with the exception of the California Department of Fish and Game which at first did not fully recognize the impact of sea otter foraging on the human exploitation of shellfish fisheries. Although details have changed over time, the basic positions of other groups (e.g., conservation groups protecting the animal, commercial fishing interests) have remained essentially unchanged. The controversy has also been punctuated by a number of scientific debates, many of which still persist. Most prominent among these are the taxonomic status of the sea otter, its role in structuring the nearshore environment, its impact on shellfish resources, and its susceptibility to oil pollution and other environmental hazards.

Analysis of the current management framework reveals a complex and somewhat confusing diffusion of responsibilities for sea otter research and management throughout the U.S. Fish and Wildlife Service, with subsidiary roles being played by the U.S. Marine Mammal Commission and by the California Department of Fish and Game, and with other agencies playing key roles over related marine resources (e.g., the Bureau of Land Management and oil resources). The lack of a clear focus of authority on sea otter issues within the U.S. Fish and Wildlife Service, state and federal conflicts over who should have management authority, the slow pace and unclear procedural elements characterizing the recovery plan process under the Endangered Species Act — are all administrative factors that have baffled local groups not accustomed to dealing with the intricacies of federal government bureaucracy and have confounded their efforts to provide public input into agency decisions. The administrative complexity has probably, in fact, worked to exacerbate the conflicting nature of the issue by making the administrative process appear unduly "mysterious," protracted, and impenetrable.

In addition to analyzing the administrative history and current management framework for sea otter management, this research also reviewed the array of existing management options and detailed the management preferences of different interest groups and government agencies. An evaluative framework on the basis of which alternative management options could be assessed was also presented. The major proposed evaluative criteria included biological protection, socioeconomic impact, technological feasibility, administrative feasibility, enforcement feasibility, and administrative costs.

The results of this Sea Grant research on the administrative history and management framework concerning the sea otter/shellfish fisheries conflict were directly applied in a public education conference designed to elucidate the sea otter issue and to facilitate its resolution. I cosponsored the conference with the California Sea Grant Marine Advisory Program and the Santa Barbara Museum of Natural History in January 1981. This conference, "Management of Sea Otters and Shellfish Fisheries in California: Policy Issues and Management Alternatives," held January 9-11, 1981 in Arroyo Grande, California, was designed to achieve three major goals.

The first goal was to apply the interdisciplinary knowledge resources of the university to better understand the philosophical, social, economic, and political differences that underlie the sea otter/shellfish fisheries conflict. This was accomplished through papers and discussions by a variety of social scientists and humanists who provided fresh insight and novel perspectives on a subject area — marine mammal/fisheries interactions — that had traditionally been discussed primarily from a biological perspective.

Second, we sought to provide a neutral meeting ground for groups holding divergent points of view on the issue and to foster interchange of information among government agencies, academics, special interests, and the general public. This was accomplished through intensive workshop discussions of both the broad philosophical issues involved in the controversy as well as of specific management options. As each workshop included representatives from all sides of the issue, this was the first occasion for many to interact closely with apparent "opponents." In the evaluations we received after the conference, most observers praised us on the usefulness of the workshop approach, commenting that it fostered the identification of potential areas of compromise among otherwise mutually antagonistic groups.

The third objective was to inform and educate the general public. Although the resources at stake are common-property resources, the general public has seldom been involved in discussions of marine mammal/fisheries conflicts. Involvement of the general public in this issue was accomplished through extensive advertising of the conference throughout the state and through a public comment session during the conference.

The results of our Sea Grant research were used in the conference effort in three major ways: first, directly, as a paper presentation on the management issues and options on the "Management" panel; second, to better structure the conference format and sessions (given our knowledge of the issues and actors); and third, to prepare the background materials for the conference and the discussion questions which served as the focus for deliberations in the workshop sessions.

The conference was attended by approximately 300 participants from local, regional, state, national, and international locations. Following the meeting, we received very positive feedback on the conference effort in media reports and in evaluative letters representing all sides of the spectrum (e.g., government officials, environmental groups, and the fishing community).

In conclusion, I feel that this Sea Grant research as well as the conference effort has facilitated the eventual resolution of this controversial issue. The conference discussions worked as a catalyst in bringing together mutually antagonistic groups. Following the conference, these groups have met together on various occasions to discuss methods of reaching a mutually acceptable solution to the issue. Specific governmental actions incorporating a number of suggestions proposed at these meetings have subsequently followed. While the issue is still far from being fully resolved, movement toward a compromise solution has definitely occurred. These developments are discussed in the epilogue of the proceedings of the conference (*Interdisciplinary Perspectives on Marine Mammals/Fisheries Interactions*) which we are currently completing.

With regard to the national part of our Sea Grant research, the following tasks were accomplished. The congressional passage and national implementation of the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA) were studied through analysis of congressional hearings on the passage of the two acts, congressional oversight, appropriations, and amendments of the acts, agency internal memoranda and other reports, and interest-group literature concerned with these two pieces of legislation. To supplement these sources of data and to lend further depth to our understanding of the dynamics of the passage and implementation of the ESA and MMPA, we conducted a series of personal interviews in Washington, D.C. with agency personnel, interest-group spokespersons, and congressional staff members involved with these two acts.

These data are now being analyzed. A number of scholarly journal articles comparing the political dynamics involved in the passage and implementation of the MMPA and ESA to those present in the passage and implementation of the Fishery Conservation and Management Act (which were studied in previous Sea Grant work) are being prepared.

Cooperating Organizations
Bureau of Land Management
California Abalone Association
California Council for the Humanities
California Department of Fish and Game
Center for Coastal Marine Studies, UCSC
Friends of the Sea Otter
League of Women Voters
National Marine Fisheries Service
Nautilus Press
Pacific Coast Federation of Fishermen, Inc.
Save Our Shellfish
Sea Otter Management Eduction
Senate Office of Research
U.C. Cooperative Extension
U.S. Fish and Wildlife Service
U.S. Marine Mammal Commission
West Coast Fisheries Development Foundation

Publications

CICIN-SAIN, B. In press. 1981. Sea otters and shellfish fisheries in California: management framework and options. In *Interdisciplinary Perspectives on Marine Mammals/Fisheries Interactions*, B. Cicin-Sain, P. Grifman, and J. Richards, eds. Marine Policy Program, University of California, Santa Barbara.

GRIFMAN, P. 1980. Framework for policy evaluation: an application of the marine mammal protection act of 1972. University of California at Santa Barbara.

GRIFMAN, P. 1981. In *Preserving vulnerable species: the U.S. Fish and Wildlife Service*. University of California at Santa Barbara.

MANNING, L. 1981. Richard Nixon and the endangered species act of 1973: a study of his divided goals and economic use of power. University of California at Santa Barbara.

COASTAL TRANSIT SERVICE OPTIONS AND POLICY

San Diego State University
R/MA-10
1980-82

James H. Banks and Frederick P. Stutz

Major goals of the project were to conduct a survey of existing transit service in coastal areas and to develop a set of planning guidelines relating to the feasibility and design of coastal transit services.

The coastal transit survey involved establishment of contacts with planning agencies and transit operators in coastal areas, follow-up letters, telephone conversations, and personal visits intended to gather information about the design and operating characteristics of coastal transit services.

There are a number of different types of coastal transit services, each type tends to be most successful at a particular type of coastal recreation site. Urban and suburban day-use sites are normally served by regular transit services, remote day-use sites near large urban areas by access-oriented seasonal express services, and densely developed resort communities by circulation-oriented seasonal services. Park-and-ride shuttles have been attempted at congested urban/suburban day-use sites and in places where there is no other vehicular access to the immediate vicinity of the shore, but have usually been successful only in the latter case.

Two potential roles in the overall coastal access system are commonly suggested for transit services. Their main function may be to provide access for transit dependents (that is, those without access to automobiles) or it may be to relieve parking or traffic congestion by providing an alternative to automobile access. Coastal transit services appear to be fairly effective in providing access for transit dependents, but they do not often seem to be successful as an alternative to automobile access or seem to result in a significant reduction in congestion.

There appear to be few significant differences in the design and operating characteristics of regular transit routes in coastal areas as opposed to noncoastal routes in the same metropolitan areas. There do appear to be some operational problems which are characteristic of the coastal environment. These stem from highly variable demand and traffic congestion and include overcrowding and difficulty in maintaining schedules.

Operating results (ridership, costs, and revenues) for specially designed seasonal services are reasonably similar to those of other transit services, although there does appear to be some tendency for ridership to be low and, consequently, cost per passenger to be high. Also, in some cases, seasonal services are able to achieve significant cost savings compared to regular transit operators through use of low-wage non-union labor.

Planning guidelines for coastal transit services have been prepared on the basis of the results of the coastal transit survey, general literature related to transit system planning and design, and the results of four transit planning case studies at coastal sites in the San Diego area, one of which involved evaluation of an experimental parking shuttle service that was operated in a beach area during the summer of 1982. The planning guidelines are to be published in the form of a planning manual for coastal transit services. The guidelines cover the role of transit service in providing access to coastal sites, site types and type of service, design characteristics, institutional arrangements, marketing, and evaluation.

Cooperating Organizations

Division of Mass Transportation of the California Department of Transportation

Information used in the coastal transit survey was provided by approximately 50 organizations, including the National Park Service, state departments of transportation, state park agencies, local governments, local planning agencies, and transit operators.

Publications

Banks, J. H. and Stutz, F. P. 1981. Coastal transit service and environmental management. In *Proc., Fourth Annual Applied Geography Conference.* Tempe, Arizona, October 1981.

Banks, J. H., Stutz, F. P., and Jabbari, I. 1982. Coastal transit options and policy. California Sea Grant Interim Report, San Diego State University, Center for Marine Studies.

Jabbari, I. 1982. Coastal transit service options in northern California. M.S. thesis, San Diego State University, Civil Engineering Report Series No. 82181.

LAW, ECOLOGY, AND ECONOMIC CHANGE; THE CALIFORNIA FISHERIES, 1850-1980

University of California, Berkeley
R/MA-13
1981-82

Harry N. Scheiber

As anticipated, the project is producing data and analysis of interest to public policy officials and fisheries industry officials by its application of historical and legal research methods to the history of state law and public policy. Work in progress reveals important continuities and discontinuities in the history of policy. The California sardine depletion and the governmental and institutional responses to the crisis offer a case study that will illuminate the genesis of present-day cooperation among industry, scientific, and governmental agencies. The larger question — how law provides a framework for resource exploitation, with what results under changing political, economic, and social conditions — is being illuminated by the project study in all its aspects. It is anticipated that several significant publications will result from the work; already, in 1983, lecture and seminar presentations in university and conference settings have evoked an interested response from academic and public officials alike.

Throughout 1981-82, the project leader and the trainee conducted research on the history of resources law at the University of California (UC) Berkeley's Boalt Hall and in libraries at Monterey, Scripps Institution of Oceanography (SIO) in La Jolla, Sacramento, and the San Francisco Bay Area. Out of that work has come, in particular, an understanding of the importance of the initiative and referendum process in California resource-law history, which we have decided to make an independent project for purposes of publication and which is nearly completed. We have also made a very promising start on the history of the Marine Research Committee, its relationship to the sardine crisis and the Scripps Marine Life Program, and the origins of CalCOFI — all illustrating the record of interplay among scientists, policy makers, and the industry in the period from 1946 to the present. SIO Archives were indispensable.

The associate investigator spent the summer and fall of 1982 on leave from Northwestern University as a research appointee at Berkeley; he continued his own main project on the book manuscript and joined in the research on the post-1945 period. He further pursued the material available at SIO Archives, but he also investigated documents housed at California State Fisheries Laboratory, Long Beach, and he conducted interviews with Drs. Richard Croker and Francess N. Clark on the record of their careers with the state Department of Fish and Game.

In September 1982 the first formal results of the post-1945 period joint study were presented at NMFS-SWFC, La Jolla, by the associate investigator. In November 1982 the project leader and associate investigator will present a more developed version of this analysis, largely based on manuscripts in SIO Archives, at the Law and Society Center, School of Law, UC Berkeley. In October 1982 the associate investigator spoke at CalCOFI at Idyllwild, on "Scientific Research and the 20th Century Fishing Industry," a study of institutional and ideological barriers to the effective implementation of scientific knowledge in managing the sardine fishery. There was a full discussion by conference participants, centering on the capacity and responsibility of scientific workers in taking active roles in policy phases of fisheries management. The associate investigator has also held discussions with federal officials (NOAA, USFWS) concerning the historical and legal backgrounds of the Klamath River suit concerning the NMFS 1982 management plan for ocean salmon and alleged infringements of Indian rights.

The project leader has presented results of his own and joint research (with the associate investigator, the trainee, and with both) in several lectures held at Stanford University, Harvard University, UC Berkeley, and the International Economic History Congress, Budapest.

In the second year of the grant, 1982-83, it is anticipated that both the projected major book and several articles will be completed and ready for publication.

Cooperating Organizations
California Department of Fish and Game
National Archives and Records Service, San Bruno
NOAA
Scripps Institution of Oceanography
University of California
USFWS, Arcata

Publications

McEvoy, A. 1982. Scientific research and the 20th-century fishing industry. Report 23. CalCOFI.

Scheiber, H. N. 1982. Lectures at Stanford University, December 1981 and at Harvard University, May 1982 on the history of California resource law. (Also in Budapest, Hungary, on a related theme, August 1982.)

Scheiber, H. N. In press. 1983. Public rights and the rule of law in American legal history. Boalt Hall Centenary Lecture, April 1982, at the School of Law, Berkeley.

THE POLITICS AND POLICY IMPLICATIONS OF DEEP SEABED MINING: U.S. OPTIONS

University of California, Santa Barbara
R/NP-1-81
1980-81

Dean E. Mann and Kurt M. Shusterich

This report summarizes the research findings from four major areas of the project. The first was an analysis of the ocean mining industry. This industry was found to have been successful in influencing U.S. ocean mining policy at both the legislative level and at the Third United Nations Conference on the Law of the Sea (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 a Law-of-the-Sea (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 of 20-30% on their investment 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 they have not progressed further primarily because of the poor metals market and low returns on investment.

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 was 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 proindustry 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 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) an increase in the number of technocrats involved in several bureaus associated with ocean policy formation.

A third area of the project dealt 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 dealt 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 ISBA. 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, the findings of the study 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
Department of Commerce
Department of the Interior
Massachusetts Institute of Technology
State Department
University of Southern California
U.S. Congress

Publications

Shusterich, K. M. 1981. The politics of deep seabed mining: a case study in international resource management. Ph.D. dissertation, Political Science.

Shusterich, K. M. In press. Mining the deep seabed: a complex and innovative industry. Marine Policy.

MOBILE MARINE SCIENCE OUTREACH PROGRAM

California State University, Long Beach
R/NP-1-9J
1980-81

Roger D. Bauer

The mobile marine van was developed as a means of taking information and educational materials about our marine resources directly to the general public. To achieve this end, a 26-foot van was converted to a mobile science museum. For 2 years the van visited schools, public places, and community groups giving people an opportunity to learn about marine science and the marine environment.

A workshop was held on July 2, 1980 to develop display ideas and methods. This was co-sponsored by the Marine Advisory Program. A total of 19 individuals attended including 9 faculty; 2 advanced science students; Dr. Norma Wilbur, Superintendent's Office of Los Angeles County Schools; Barbara Katz, Area Marine Advisor; Dale Ingmanson, Sea Grant College Program; and Arnie Korporaal, Superintendent's Office of Los Angeles County.

A variety of display materials in marine science were prepared. Mike Schaadt, a graduate student in marine biology at CSU Long Beach, was employed to develop and to coordinate the development of displays. When this grant expired, Schaadt was placed on the school staff to carry out these activities on a part-time basis.

The mobile museum visited 13 schools and a number of other sites including the Los Altos Shopping Center, Girl Scouts of Long Beach, and the Long Beach Recreation Department. The displays were consistently well received regardless of the age or educational backgrounds of the participants.

One of the "grabber" displays involved shark jaws and fins. This display was always effective in attracting visitors when placed near the entrance to the museum.

An effort was made to allow the participants "hands on" activities. This included a touch tank which contained many specimens found in local tidal areas. The preparation of a cooled saltwater system presented some special difficulties which were surmounted ultimately. Colored photographs of our specific displays were prepared and mounted adjacent to the touch tank. This allowed the participants to identify the various specimens themselves. The photographic display is shown in figure 1.

The mobile museum activities were as well received and exciting as we had projected when we initiated this program. The responses we received from participants were most gratifying. We were especially pleased to receive a grant from the ARCO Foundation to help continue the activities of the museum as this initial grant expired.

BIOELECTRIC TOXICITY ASSAYING (PHASE I)

University of California, San Diego
R/NP-1-9M
1980-81

Victor C. Anderson

The 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 received with an array of silver-silver chloride electrodes, recorded, and analyzed for changes in amplitude, spectral content, and spatial correlation, in response to chronic exposure to pesticides.

In preparation for the experimental measurements, we have maintained 10 *Cerithidea californica* in an 8-liter aquarium for a period of 100 days to evaluate them as test species for use with the array.

The electrode array design was modified to eliminate the agar well used in preliminary work. This design was considerably easier to fabricate, but still required a man-month to complete. The new design has a single 0.5-mm hole per electrode and the back side to the array is sealed with a soft silicone potting compound. The 272 outputs of the array are hardwired to the low-noise preamplifiers.

In the 272-channel preamplifier, oscillation became a problem as more channels were connected. This necessitated the redesign of the preamplifier printed circuit boards to include a ground plane. The combined array of silver electrodes and preamplifiers has been tested and found to perform excellently.

The multiplexer is 75% completed and connected to the outputs of the preamplifier. Channel isolation is satisfactory and the design has been verified so that completion is straightforward. The nearly completed myoelectric array system is shown in figure 1.

The equipment is now being interfaced to a PDP 11/15 computer for data recording and processing. Throughout the integration of this system both electronic signals and live gastropods have been used to verify the design. Most of the software for data collection and analysis is precanned, so the programming task for data collection and analysis is nearly complete.

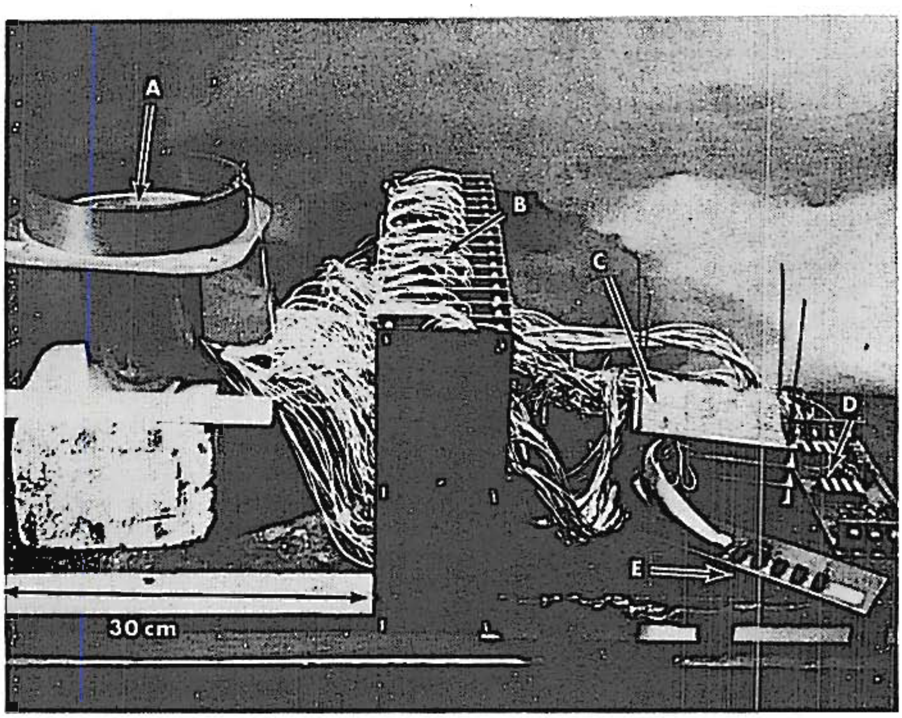


Figure 1. Myoelectric array system. A) 272-element silver-silver chloride sensor array. B) 272-channel preamplifier bank. C) 256-channel to 4-channel multiplexer. D) 4-channel rapid zeroing amplifier. E) Address interface for multiplexer.

A PRELIMINARY INVESTIGATION OF INDOCHINESE REFUGEE ADAPTATION TO THE MONTEREY BAY FISHING INDUSTRY

University of California Santa Cruz
R/NP-1-9N
1980-81

Michael Orbach

The major goals of the second phase of our Rapid Response Indochinese project were as follows: 1) to conduct a preliminary investigation into the relationships between harvesting, processing, and other sectors of the Monterey Bay fishing industry and related agencies and organizations as they apply to new entrants such as the Indochinese; 2) to outline the historical and existing relationships between various social and cultural groups within the Monterey Bay fishing industry, with special attention to the history of present and potential Indochinese participants; 3) to apply the results of the above work to current deliberations by various local and state agencies concerning new restrictions on gill-net fishing, the primary fisheries in which the Indochinese participate.

Based on our 1980 work with the Indochinese community and preliminary interviews throughout the Monterey Bay area with individuals knowledgeable about the Indochinese situation, we developed an open-ended interview instrument that addressed issues of perception and opinion concerning Indochinese participation in the local fishing industry, problems that have arisen from this participation and their potential solutions, and attitudes about Indochinese immigrants in general.

The instrument was used in interviews with 35 representatives of local fish buyers, merchants, service industry personnel, social service agencies, the media, non-Indochinese fishermen, and management and law enforcement agencies. The interviews yielded a picture of a local community and industry divided within itself concerning the real or potential impact of the Indochinese on the local fishing industry and community, as well as several severely distorted perceptions of Indochinese attitudes and life-style and the kinds and degrees of services available to the Indochinese from various government agencies. In addition, there was an apparent sharp division of attitudes between non-Indochinese interviewees in Monterey and Moss Landing.

On September 18, 1980 Governor Jerry Brown signed into law a bill introduced by a southern California assemblyman and co-authored by another southern California assemblyman. The bill, Assembly Bill 2566, dealt with the issue of licenses for commercial gill-net fishing. It provided for revocable, nontransferable licenses to be issued by the state. The normative basis for the new law was this: "The Legislature finds and declares that it is in the best interests of the people of the state, the commercial fishing industry, and California's marine resources that fishermen who use gill nets be experienced in the use of such nets" (A.B. 2566). The bill also provided that, "The Director (of the Department of Fish and Game) shall establish an advisory committee, consisting of fishermen experienced in the use of gill nets, to advise the department in developing regulations to be proposed to the (Fish and Game) commission governing the use of gill nets."

Although it came at a time very crucial to the entry of the Indochinese — who use gill nets almost exclusively — into California's fishing industry, the development of A.B. 2566 had virtually nothing to do with the Indochinese. The bill was generated out of a series of conflicts that had arisen between sports fishermen, environmentalists, and commercial gill-net fishermen in southern California. Commercial gill-net fishermen would either target on fish species that were also prized by sportsmen or, as in the case of gill-netting shark and swordfish, would also inadvertently ensnare marlin and other highly prized recreational fishery species. These conflicts, in addition to a general distaste for gill-net fishing resulting from the "ghost net" phenomenon, prompted the assemblymen to initiate the legislation. It is important to note that traditionally the northern and southern portions of California have been quite different political arenas, with different issues and opinions characterizing the two portions. The fishing issues that generated this legislation were typically southern Californian.

The Indochinese in fact have a representative on the gill-net advisory committee, but this has proved to be of only marginal benefit. There is now activity in the California legislature to consider even more restrictive laws and regulations concerning gill-netting, particularly in the Monterey Bay area. We have recently been contacted by representatives of the Indochinese community for advice on this matter and for copies of our work, which they wish to distribute to the local legislators to ensure that the legislative staffs are properly informed from <u>all</u> perspectives on the current situation and issues. As we pointed out in the report from the first phase of our project, the problems of the Indochinese will continue for some time to come, and we expect to structure our applied social research efforts to aid in the rational and fair resolution of these problems.

Cooperating Organizations
Monterey Bay Counties' Refugee Services Program

Publications

ORBACH, M. K. In press. The logic of social systems analysis in the coastal zone: the case of the Indochinese refugees. Coastal Zone Management Journal.

ORBACH, M. K. AND BECKWITH, J. Submitted. 1981. Indochinese adaptation and local government policy: an example from Monterey. Anthropological Quarterly.

ORBACH, M. K. AND BECKWITH, J. 1981. New country, new community, old occupation: the Indochinese fishermen in Monterey Bay. In *Day on the Bay*. Center for Coastal Marine Studies, Santa Cruz.

ORBACH, M. K. AND BECKWITH, J. 1981. Report on the adaptation of Indochinese refugees to the fishing industry and community of Monterey Bay. Center for Coastal Marine Studies, Santa Cruz.

APPLICATION OF ADVANCED METHODS OF MAGNETIC RECONNAISSANCE

University of California, Santa Barbara
R/NP-1-10A
1981-82

Ken C. Macdonald and Steven P. Miller

The objective of this research study is the application of advanced methods of magnetic interpretation to crustal structures in the southern California borderlands area. The magnetic analysis involves the use of two-dimensional (2-D) forward modeling and inversion and three-dimensional (3-D) forward modeling and inversion.

The 2-D analysis is applied to fault-related features in the borderlands region; given reasonable models of magnetization vectors for opposing crustal blocks, 2-D modeling is used to locate a fault. The analysis is first applied to a well-located, known fault and then extended to an area where fault location is less precisely known.

The 3-D forward modeling and inversion techniques are applied to specific bathymetric features to extract the local magnetizetion vector and accurately correct for topographic effect. One target, San Clemente Island, is being analyzed to provide a "ground truth" test for the method. The magnetization vector extracted from aeromagnetic data over the island will be compared with the paleomagnetic vector obtained directly from rock samples collected on the island.

Although only preliminary results have been attained for each fault of this research project, it is possible to draw some important implications from these results.

Concerning the analysis of fault-related features, the San Clemente Excarpment Fault is being analyzed directly northwest of the island and southeast of the island through San Clemente Canyon and San Clemente Rift Basin. Forward modeling of two profiles perpendicular to San Clemente Canyon 15 and 20 km southeast of the island indicates that magnetic anomaly patterns are not attributable to the San Clemente Escarpment Fault, recognized in seismic reflection records. The fault cannot be located on the basis of the magnetic measurements available for this study; although with a continuous recording of the magnetics along this profile it may be possible to pinpoint the fault. This is being attempted along two other profiles approximately 40 km southeast of the island through San Clemente Rift Basin. For one profile the data was provided from NOAA from the CONMCALF Cruise in 1970. The other profile is from data collected aboard the R/V Thomas Washington in June of 1982 by Scripps Institution of Oceanography (SIO) and Bruce Luyendyk. Both forward and inverse modeling techniques are planned for these data sets. The profile directly northwest of San Clemente Island does offer the possibility of a strong correlation between magnetic anomaly pattern and fault trace. Forward and inverse modeling of the data along this profile are in progress.

The implication is that in the southern California borderlands region the analysis of magnetic anomaly patterns can be only a supplemental tool in the location and mapping of faults and fault-related features. This is mainly due to the primarily northwest-southeast trending strike-slip nature of faulting, which may or may not juxtapose rocks of contrasting magnetic properties. However, these methods may be useful for identifying rotational strain of crustal blocks, areas of dip-slip faulting, and areas of strike-slip faulting where the magnetic properties of adjacent crustal blocks are different.

Another major facet of this research project is the analysis of the total magnetic vector over specific isolated features. Rodriguez Seamount, San Juan Seamount, and San Clemente Island were chosen as targets for various reasons among which were the interesting magnetic anomaly patterns, the availability of quality data, the simple geometry and supposed simple geology of each target. Unfortunately, the 3-D forward modeling completed to date has yielded ambiguous results.

Rodriguez Seamount and San Juan Seamount may turn out to be simple case studies; however, problems have been encountered in accurately defining and removing the regional magnetic gradient; this partially attributable to the Patton Escarpment in the vicinity of each seamount. The magnetic analysis is continuing; a technique for 3-D inversion has recently been acquired with plans for application to the seamount data. Optimistically, the intent is to help verify that Rodriguez Seamount and San Juan Seamount are oceanic in origin and to determine whether or not they have been rotated.

Analysis of the aeromagnetic data available over San Clemente Island has provided more questions than answers. The assumptions of simple bodies and uniform magnetization to define the island has proven to be unrealistic. A more sophisticated model of the island is being developed, taking into account the possible magnetic contrasts on the island itself and at depth, as well as the effects of faults crosscutting the island in an east-west direction. Some constraints on the variation of magnetic properties and on the structural complications of the geology of the island may be provided by the work in progress of Marc Kamerling, formerly at the University of California, Santa Barbara (UCSB).

So far, the only conclusions to be drawn from this study are that, due to the complex geologic setting in the southern California borderlands, the analysis of magnetic anomalies yields minimal results of a definitive nature and, due to its indirect approach, magnetic analysis can only be a supplemental tool in geologic interpretation. We hope that more positive conclusions will result from our continued modeling as described in this report.

Cooperating Organizations

National Geophysical and Sdar Terrestrial Data Center, NOAA
Scripps Institution of Oceanography
U.S. Geological Survey

SEASONAL GROWTH RESPONSES OF VEGETATIVE AXES AND SPORES OF AN AGAR-PRODUCING MARINE ALGA

University of California, San Diego
R/NP-1-10B
1980-81

Joan G. Stewart

This project was designed to assess potential for vegetative growth throughout a year in an agar-producing marine alga. Several other questions about regeneration, spore germination, and relative growth rates under different experimental conditions were considered in the 1-year research plan. This species, *Pterocladia capillacea*, has a life history that corresponds to perennial terrestrial plants, yet there was evidence that a seasonal or monthly cycle in vegetative growth might be lacking. To test this idea, vegetative tips were cut from field-collected thalli 11 times, in 10 of the past 12 months, and grown under six different sets of laboratory conditions. These apices were measured biweekly for up to 14 weeks, or as long as growth continued. Each time that tetrasporangial plants were found in the natural population, an attempt was made to germinate spores. Regrowth of basal "rhizoids," the prostrate branches that propagate the plants vegetatively, was examined each time apical cultures were established. Throughout the year, the growth of contaminant epi- and endophytic algae under the different conditions was recorded.

This briefly summarizes the purpose, method, and scope of the project. The following sections will describe these three aspects in somewhat greater detail and conclude with a list of tentative results.

Pterocladia capillacea is a warm-water red algal species closely related to *Gelidium*, a well-know source of agar. It grows along the coasts of the Mediterranean, Japan, Baja California, California, New Zealand, and the Hawaiian Islands and is brought to San Diego in the form of dried, baled seaweed for processing at American Agar (Difco Co.). Other colloid businesses likewise buy naturally grown *Gelidium* and *Pterocladia* thalli. Worldwide, agar-producing seaweeds occur in limited and uncertain supply, resulting in recent huge increases in the price of the manufactured product. Attempts to cultivate several *Gelidium* taxa in small-scale projects have been discouraging primarily because of very slow growth rates and because it was thought probable that, whether the species under study was an annual or long-lived, a single annual peak in growth was to be expected. Because *Pterocladia capillacea* on the U.S. coastline occurs only as far north as Santa Barbara in California, and is abundant and widely distributed largely in San Diego County, it has not been included in prior studies and its growth characteristics had not been separately evaluated. It is, however, considered a perennial species, on the basis of studies in Europe and California. Vegetative thalli are most abundant in late fall and winter on the Channel Islands off California and in San Diego County, although the amount of rock substrate covered by the persistent basal and prostrate branches remains constant. It is not known what factors contribute to the apparent annual fluctuations in the size of the plants.

To establish whether the vegetative growth of this species was regulated by intrinsic mechanisms that produced seasonal or monthly differences in elongation rates of axes, plants from the same population were collected during low tides on successive months, beginning in October, 1980. Apices, 3 mm long and including a single primary apical cell and, insofar as possible, unbranched, were cut from these plants and divided into six "treatments" as shown in figure 1. These apical portions were individually measured; early and incomplete data for October-January collected thalli are included in the figure. Subsequent measurements, through December 1981, will be incorporated into final graphs. This set of data constitutes the major positive result of the work. Information has also been obtained concerning relative importance of several means of reproduction and propagation, and common endo- and epiphytic contaminants were identified. All work utilized static cultures in enriched natural seawater medium — definitely a nonoptimal system for a plant the size of *Pterocladia capillacea*. It is likely that the growth increments indicated on the vertical axes of the graphs represent minimal rates more than maximal. Because of the unfavorable and variable conditions inherent in the experimental system, the absolute values are clearly of little significance. The important trends are the similarity of the curves in any single condition and different slopes under different conditions.

The trends already observed after 4 months persist in later data. The following conclusions must still be confirmed by analyses of final complete data sets.

1) *Pterocladia capillacea* shows no seasonal or monthly cycle of intrinsic vegetative growth potential that would correspond to seasonal optima of many terrestrial perennial plants.

2) Growth rates, as predicted from studies of related genera, were uniformly very slow.

3) Increased growth was correlated with increased water temperatures between 10 and 20°C; longer light periods favored growth.

4) Attempts to germinate tetraspores were unsuccessful, while rhizoids both regenerated and initiated growth at all seasons. This substantiates the opinion that vegetative propagation will be useful in any management program involving this alga.

5) Five important contaminating epi- and endophytes were recognized that presumably would be major competitors for nutrients in culture systems.

6) Healthy thalli, useful for transplants or inocula, can be maintained in running seawater in low light for up to several weeks.

7) Standard static culture techniques, despite anticipated limitations, provided useful information about this macroalga.

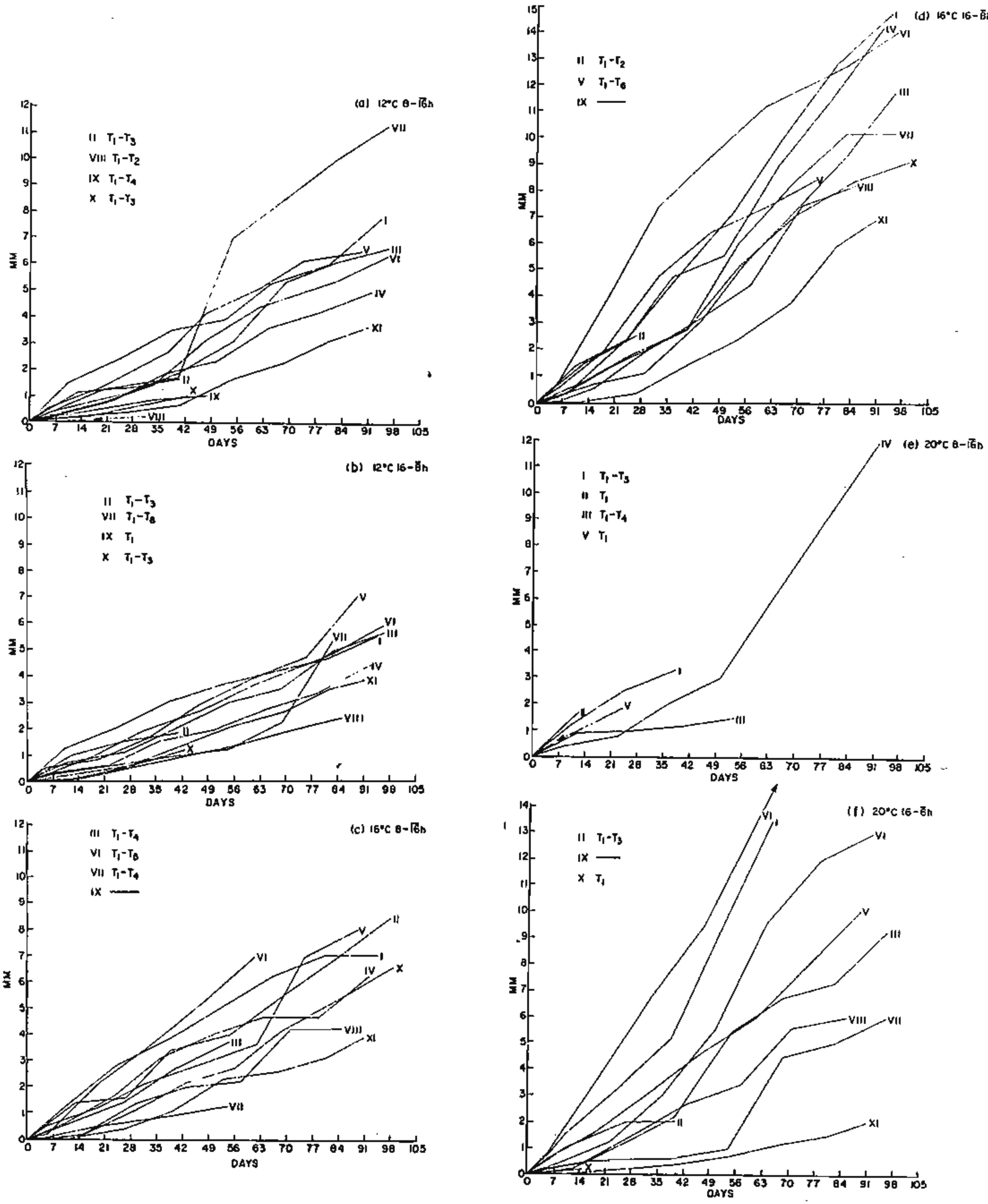


Figure 1. Relative growth of first four sets of *Pterocladia capillacea* cultures, March 1981.

Publications

STEWART, J. G. Preliminary Report. Presented at Hopkins Marine Station at a Sea Grant Subject Area Meeting, March 1981.

STUDIES OF LIGHT AND LIFE IN NATURAL WATERS

University of California, San Diego
R/NP-1-10C
1980-81

John E. Tyler

This project was in the form of a symposium held on December 29, 1980. The symposium was held in Seattle, Washington and was hosted by the University of Washington.

To understand the goal of this symposium, it is necessary to recall the early research on the spectral visibility of the human eye that was initiated in about 1917 at the U.S. Bureau of Standards. This research resulted in the definition of the lumen (as well as other visual units such as the lux) in 1931. These units were developed in order to specify that portion of the light from any source that was visible to an average, young human eye.

It was also in the early 1930s that an international group of biological oceanographers searched for a light measurement that would make it possible to relate phytoplankton photosynthesis with available light at different locations and depths in the ocean.

In 1936-37 a special conference for the discussion of submarine daylight was organized at the International Council for the Exploration of the Sea. This conference was attended by both physicists and biological oceanographers, the intent being to achieve a standardization of submarine light measurements for correlation with oceanic photosynthesis.

It is obvious today that the physicists at that meeting did not understand the true needs of the biologists and the biological oceanographers did not understand the lux unit developed and defined by the physicists. The unfortunate result of this conference was the adoption of the lux unit for correlation with photosynthesis in the ocean.

This misunderstanding resulted in what has been called "the dark ages of biological oceanography" during which phytoplankton photosynthesis has been persistently and incorrectly correlated with the spectral region of natural light that is least absorbed in photosynthesis.

This gross error has persisted into the 1970s as a habitual disinclination to accept the teachings of E. Steemann Nielsen (1957), Eugene Rabinowitch and Govindjee (1969), and the Stark-Einstein Law. For the past several years I have been called upon to review, and have rejected, manuscripts based on this misconception that have been submitted for publication in the scientific literature. The cost of this misconception in terms of research effort has been carried by research funding agencies and has been enormous.

The Seattle symposium was arranged to demonstrate the current and correct approach to the study of the interaction between light and photosynthesis (speakers: T. T. Bannister, C. Yentsch, R. C. Smith, N. A. Welschmeyer, and C. R. Booth) and to demonstrate the gross errors associated with the correlation of photosynthesis with lux units (speaker: J. E. Tyler).

AN ISOTOPIC ARAGONITE-WATER TEMPERATURE SCALE DETERMINED FROM SELECTED SHELL-BEARING MARINE ORGANISMS

San Diego State University/ University of California, San Diego
R/NP-1-10D
1980-81

Charles Shull and John S. Killingley

The first phase in the work of the project was obtaining and fitting appropriate laboratory space with an aquarium to grow experimental specimens of shell-bearing marine organisms. Although agreement had been reached for the use of a portion of the bivalve laboratory being set up by Drs. Phleger and Leighton under the pier at Scripps Institution of Oceanography in November 1980, the laboratory was not ready for use until late May 1981. At this time it was immediately stocked with several specimens each of about a dozen species of mollusks. Temperature recording apparatus was acquired and installed and sampling began on several of the species and has continued to the present.

The stable isotopes of oxygen and carbon have been determined for species of shell-bearing marine organisms, about half of which possess aragonite mineralogy and half of which possess calcite mineralogy. The initial list of species examined consisted of the following:

Aragonite:
- *Kelletia kelletii**
- *Tegula regina**
- *Megathura crenulata*
- *Serpulorbis squamigenus**
- *Serpulids*

Calcite:
- *Mytilus californianus**
- *Mytilus edulis**
- *Littorina planaxis**
- *Haliotis fulgens*
- *(Chione californiensis)*

The species marked with an asterisk showed the most promise in terms of rate of growth in the aquarium and so became the species subjected to systematic analysis.

Growth periods are represented in table 1, where the values for several specimens of each species are recorded for the time intervals involved. Column I lists values obtained from specimens sampled at the time of acquisition and is headed "Initial Value." Because the ambient temperature in which these specimens had grown was unknown, little can be said about the temperature changes except that it appears that they came from a colder region.

The aragonite has an average value of $\delta^{18}O$, about 1 part per thousand heavier than the calcite group. This is consistent with general observations that the aragonite temperatures (calculated from paleotemperature equations) appear "colder" than calcite.

There are two important characteristics of temperature change during the interval reported here.

First, the total average temperature change from June 1 to October 1 was -1.4°C, which, if precisely reflected in isotopic composition, would mean a change of about +0.35 parts per thousand. The spread of values for a given species over the temperature range is seen to be as high as 0.5 parts per thousand and with no consistency with respect to direction. The temperature effect in this range (20.4 - 19.0°C) is obscured by experimental uncertainty.

A second characteristic of the temperature in the interval reported is a rather large short-period variation of as much as 7 degrees leading to rather large standard deviations of the average. This property of the temperature history has an unknown effect on the growth of the specimens and may contribute to the scatter of data points.

It is expected that in the coming months the change in the average temperature will be much greater and at the same time the range between maximal and minimal temperatures for each period of growth measurement will be smaller and therefore provide a more representative temperature in which shell growth actually takes place.

If this expectation is not realized, plans are being made to control the temperature of the water into the aquarium, eliminating the extremely low temperatures. This will maintain a more uniform temperature gradient.

Conclusion

The data reflect a definite difference in aragonite and calcite shells growing in the same environment, the aragonite $\delta^{18}O$ being about 1.0 part per thousand heavier than that of the average calcite specimen.

Continued work through the remainder of the year will provide the data for comparing the aragonite with calcite at markedly different temperatures and provide data for a complete temperature equation.

While the oxygen isotope composition seems to have a straightforward relationship to the temperature, the carbon composition is much more complex. Carbon isotope data has been gathered for all the samples but no attempt has yet been made to analyze this information.

This grant has made possible a promising start on the development of a definitive isotopic fractionation relationship to temperature for aragonite which has hitherto not been reported.

Table 1

Oxygen and Carbon Isotope Composition in ppt PDB

	Initial Value Temp= Natl. Habitat		6/5 - 6/18/81 Temp= 20.4°C		6/18 - 7/7/81 Temp= 20.4°C		7/7 - 7/24/81 Temp= 20.1°C		8/26 - 9/3/81 Temp= 19.12°C		9/3 - 10/1/81 Temp= 18.96°C	
	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$
Calcite Species												
M. californianus	-0.21	0.95	-0.88	2.10	-0.80	0.69	0.86		-0.9	-0.25		
			-0.90	0.40								
M. edulis	-0.14	1.15	-1.30	-0.57	-1.22	0.65	-1.43	0.50			-0.99	-0.51
			-1.09	-0.33	-1.36	0.25	-1.08	0.57	-1.1	-0.53	-1.21	-0.02
							-1.02	0.60	-1.47	-0.40	-1.17	0.65
L. planaxis	-0.20	1.68	-1.06	1.25	-1.16	1.14			-0.07	1.46	-0.67	0.22
			-1.37	1.00							-0.78	-0.82
Haliotis fulgens					-0.66	1.03			-0.64	1.1		
					0.11	0.78						
Aragonite Species												
K. kelletii	0.40	0.06	-0.33		-0.26	0.09	-0.04	-0.05	-0.42	1.11	-0.03	0.56
	0.31	0.53	-0.45	-0.15	-0.15	0.21	-0.01	0.07	-0.16	0.61	-0.12	0.33
	0.81	0.73	-0.21	0.46	-0.25	0.41	0.12	0.69	-0.78	0.77		
			-0.45		-0.13	-0.09	0.01	-0.15				
					-0.46	-0.36						
					-0.17	-0.03						
A. undosa	0.41	1.35	-0.51	1.04	-0.61	1.00			-0.91	1.44	-1.15	1.17
	-0.04	1.23							-0.33	1.20		
M. crenulata	-0.14	0.28										
	-0.35	0.76										
	0.48	0.47										
T. regina	0.62	0.57										
Chione californiensis	-0.45	0.39										
	0.26	0.68										
S. squamigerus			-0.78	2.80	-0.47	0.44			-0.25	2.50	-0.22	3.50
			-0.93	2.34	-0.63	0.77					-0.89	0.33
Serpulid worms					-0.30	1.24			0.51	1.31		

Cooperating Organizations
Scripps Institution of Oceanography

COASTAL ZONE GEOLOGY AND RELATED SEA CLIFF AND BLUFF EROSION: OCEANSIDE SOUTH TO BATIQUITOS LAGOON, CARLSBAD, OCEANSIDE LITTORAL CELL, SAN DIEGO COUNTY, CALIFORNIA

University of California, San Diego
R/NP-1-10E
1980-81

Francis P. Shepard

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

Objectives

The project's original goals were initiated in Sea Grant project R/CZ-43. The central objective was to demonstrate the methodology of collecting and preparing geological information essential to resource planning and management decisions. This involved the computation and use of 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. Such information was to be augmented by interviews with long-term residents, information derived from newspaper files, and collections of old photographs, together with data gathered from scientific literature. This base information was to be used as a guide to detailed field investigation and mapping.

Results

During the first 4 months of this project in 1977-78, an information data base was acquired, researched, and organized on important meteorological events (floods, storms, and earthquakes) that may have had a marked influence on the coast in past years. The winter storms of 1977-78 were destructive along the San Diego County coastline. A photographic documentation of coastal changes was conducted during and after each storm for evaluation.

During the first year, 1977-78, field mapping was followed by extensive literature and record search for all pertinent historical information on the area. In the event of heavy winter or spring storms, observations were made to determine what erosional effects have resulted. Apparent effects will be recorded photographically. During the summer of 1978, efforts were concentrated on analysis of field and historical data, and preliminary maps were prepared.

Between 1977 and 1979 the coastal zone from Batiquitos Lagoon (south of Carlsbad) to the southern boundary of Camp Pendleton (north of Oceanside) was mapped on photogrammetric maps of a 1:2,400 scale, and comprehensive geological data relevant to land use was compiled. This involved the following procedures:

1) Researching and organizing information on important past meteorological events (floods and storms) that may have had marked influence on the coast.

2) Collecting and comparing historical maps showing the shoreline features and development for comparison with each other and with modern maps to document stability or change. Old plat maps were particularly useful for this purpose.

3) Searching tax assessment records of shoreline parcels for information as to diminished land area or elimination of parcels from the tax roles as a result of inundation.

4) Inspecting newspaper files for accounts of the effects of natural events such as storms at sea, heavy rains, and earthquakes.

5) Interviewing long-time residents of coastal areas to obtain observer accounts of catastrophic changes.

6) Searching collections of historical photographs and memoirs for documentation of changes.

7) Mapping the individual geological lithologic units and their characteristics with relation to weathering processes and cliff erosion.

8) Determining the general engineering properties of the soils and rock units, particularly those types that are especially susceptible to erosion under natural, undisturbed conditions.

9) 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.

10) Monitoring the flow and effect of groundwater and induced spring sapping and piping through geological units.

11) Evaluating performance of existing shore protection works.

12) Mapping the coastline to the inland boundary set by the California Coastal Act of 1976 on a 1:24,000 scale. This scale will show the regional geology including stratigraphy and structure and will supplement the 1:2,400 scale maps. All pertinent previous geological studies will be incorporated into the phase of the study.

13) Photogeological examination and interpretation of aerial photography from earliest available photos to the present will be compared along with recent available landsat, infrared and/or near-infrared photography in order to define regional topographic lineations and alignments related to faulting and folding.

14) Identifying areas subject to slope-stability problems.

The results derived from this project were made available as they were uncovered to the California Coastal Commission, other State of California agencies, California city planners, San Diego County agencies, concerned citizens, planning groups, consulting firms, attorneys at law, corporations, high schools, and colleges. The final project results of this study are divided into two reports. Sea Grant has recently published *A Manual for Researching Historical Coastal Erosion*, written by Kim Fulton (a Sea Grant writing intern). This manual describes the methodology devised by the project leaders. The final project results of this study will be published by the U.S. Army Corps of Engineers in order to assist in future shoreline planning.

Cooperating Organizations
California Coastal Zone Commission, San Diego Region
California State Lands Commission
County of San Diego

Publications

AGNEW, D. C., LEGG, M. R., AND STRAND, C. 1979. Earthquake history of San Diego. In *Earthquakes and other perils in San Diego*, P. Abbott and W. Elliott, eds. Geol. Soc. Amer. field trip, by S.D. Assn. of Geologists.

EMERY, K. O. AND KUHN, G. G. 1980. Erosion of rock shores at La Jolla, California. Mar. Geol. 37:197-208.

EMERY, K. O. AND KUHN, G. G. In press. 1981. Classification of seacliffs. Geol. Soc. of Amer. Bull.

FULTON, K. 1981. Coastal retreat. Sea Frontiers 27(2):82-88.

FULTON, K. 1981. A manual for researching historical coastal erosion. Report No. T-CSGCP-003. California Sea Grant College Program, La Jolla, CA.

KUHN, G. G. 1977. Coastal zone geology and related sea cliff erosion, San Dieguito River to San Elijo Lagoon, San Diego County. Also funded by San Diego County contract #11596-0800E. Includes material from Sea Grant project R/NP-1H.

KUHN, G. G. 1981. Coastal erosion along Oceanside littoral cell, San Diego County, California. Sea Grant draft working paper, prepared for the California Coastal Commission.

KUHN, G. G. AND SHEPARD, F. P. 1979. Accelerated beach-cliff erosion related to unusual storms in southern California. Calif. Geol. 32(3):58-59.

KUHN, G. G. AND SHEPARD, F. P. 1979. Coastal erosion in San Diego County, California. In *Earthquakes and other perils, San Diego region*, P. Abbott and W. Elliott, eds. For Geol. Soc. Amer. field trip by S.D. Assn. of Geologists.

KUHN, G. G. AND SHEPARD, F. P. 1981. Should southern California build defenses against violent storms resulting in lowland flooding as discovered in records of past century? Shore and Beach 49(4):3-10.

KUHN, G. G., SHEPARD, F. P., AND FRAUTSCHY, J. D. 1979. Erosion threat to the coastal bluffs of San Diego County. 11(7). Presentation to the Geol. Soc. Amer. Annual Meeting, San Diego. (Abstract).

LEGG, M. R. 1980. Seismicity and Tectonics of the inner continental borderland of southern California and northern Baja California, Mexico. M.S. thesis, Oceanography, University of California, Davis.

LEGG, M. R. AND AGNEW, D. C. 1979. The 1862 earthquake in San Diego. In *Earthquakes and other perils in San Diego*, P. Abbott and W. Elliott, eds. For Geol. Soc. Amer. field trip, by S.D. Assn. of Geologists.

LEGG, M. R. AND KENNEDY, M. P. 1979. Faulting offshore San Diego and northern Baja California. In *Earthquakes and other perils in San Diego*, P. Abbott and W. Elliott, eds. For Geol. Soc. Amer. field trip by S.D. Assn. of Geologists.

LEGG, M. R. AND ORTEGA, V. W. 1979. New evidence for major faulting in the inner borderland off northern Baja California, Mexico. EOS 59:1134. (Abstract).

INVESTIGATION OF COASTLINE RETREAT, HUMBOLDT COUNTY, NORTHERN CALIFORNIA

Humboldt State University
R/NP-1-10F
1980-81

Derek Rust, Gary Carver, Lori Dengler, and Don Tuttle

The Project's original goals were as follows:

1) Produce detailed geologic and geomorphic maps of the coastline in the Trinidad and the Shelter Cove areas so that interrelationships between rock type, geomorphic setting, and failure process could be assessed, and to make comprehensive maps of the coastline available for planning land use along the coast.

2) Instrument several active coastal slope failure sites to monitor rate and amount of movement in relation to a number of controlling physical factors (e.g., rainfall and tidal changes).

3) Assemble all available historical information relating to coastline retreat in the Trinidad and Shelter Cove areas.

4) Combine all the information obtained in final reports for Trinidad and Shelter Cove. An objective of combining the information is to produce a factor analysis of the variables involved in the Trinidad area, which then might be applicable elsewhere. Comparisons of historical retreat rates with rates at the instrumented sites are another example of the benefits of a multifaceted approach.

Project Results

Geologic and geomorphic maps of the Trinidad coast at a scale of 1:6,000 have been produced and are now being drafted. The geologic maps show bedrock distribution and type, while the geomorphic maps show on a separate sheet the location and type of coastal failure process. These maps show that retreat mechanism and rate are predominantly influenced by bedrock resistance and geomorphic setting. However, because the bedrock is characteristically very variable even on a small scale, the nature and rate of coastline retreat are constantly changing as the coast recedes. This typically results in rapid retreat of certain parts of the coastline until more resistant bedrock conditions and/or until a more favorable geomorphic setting are encountered. Relative stability is then enjoyed while other parts of the coastline begin phases of retreat; ultimately the favorable conditions at the original part of the coastline are lost and it begins another phase of accelerated retreat. This picture applies over a wide range of scales in time and space.

Movement histories for seven monitored sites on two massive coastal slump-earthflows have been obtained for the 1979-80 and 1980-81 storm seasons. Preliminary analysis of this data shows a complex pattern of movement characterized by the following:

1) Numerous continually changing blocks bounded by discrete shears and slip surfaces interacting within the larger slide mass.

2) Individual and different movement histories for different blocks.

3) Movement characterized by sudden slip events resulting in a few millimeters to a few centimeters of rapid slip and separated by intervals of a few hours to several days of quiescence or very gradual continuous creep.

4) A general increase in frequency and magnitude of movement events toward the toe of the slump-earthflows.

No direct correlation between rainfall and movement patterns of the monitored sites was evident from the monitoring records, but a large proportion of the movement events occurred within a few hours of high tide. Continued monitoring efforts are underway for the 1981-82 storm season to further assess the relationship of coastal slump-earthflow movement, rainfall, and surf and tide activity.

Compilation of historical information and analysis of enlarged air photographs of the coastline covering a 50-year period show considerable variation of coastal bluff retreat rates, especially in areas of heterogeneous bedrock lithologies. Many areas, particularly those composed of massive resistant Franciscan lithologies, have remained stable during the past 50 years. The coastal reaches composed of highly sheared Franciscan melange frequently show up to 20 meters of progradation of the shoreline resulting from active advancement of slump-earthflow toes. Rapid retreat of the crest of the coastal slope by as much as 120 meters is locally associated with these active slump-earthflows. Coastal bluffs cut into poorly consolidated late cenozoic deposits have retreated between 10 and 30 meters since 1931 throughout the study area.

Cooperating Organizations
California Coastal Commission
Humboldt County Department of Public Works
Scripps Institution of Oceanography

Publications

TUTTLE, D. C. 1981. Investigation of methods for determining coastal bluff erosion: historical section. Sea Grant Report.

LONGARD TUBE SURVEY AND DOCUMENTATION, DEL MAR, CALIFORNIA

University of California, San Diego
R/NP-1-10G
1980-81

Reinhard E. Flick and B. Walton Waldorf

Del Mar and numerous other southern California communities are seeking remedies to slow the beach erosion caused by both episodic and long-term loss of beach sand. If the Longard Tube is effective in stabilizing an otherwise retreating beach, it may be a relatively inexpensive and environmentally more suitable alternative to seawalls, groins, or other more permanent structures.

To judge the effectiveness of the Longard installation, it was essential to accurately survey the tube and the adjacent beach to establish their initial configuration. This has been accomplished during the initial year of surveys. It is now essential to measure any changes in this configuration over a period of time and to relate these changes to the driving forces of waves and currents.

Cooperating Organizations
City of Del Mar
California Department of Boating and Waterways

WORKSHOP ON COASTAL WETLAND RESTORATION AND ENHANCEMENT

San Francisco State University
R/NP-1-10H
1981-82

Michael Josselyn and James J. Sullivan

A workshop was held in February 1982 at the California State University, Hayward entitled "Wetland restoration and enhancement in California." The workshop was jointly sponsored by California Sea Grant College Program, California Coastal Commission, San Francisco Bay Conservation and Development Commission, California State University, Hayward, and San Francisco State University. Seven presentations were given at the workshop.

Each paper was a review of the topic and outlined areas in need of further investigation. The papers were critically reviewed by a panel of experts who had received copies of the presentation 2 weeks before the workshop. The following is a list of panel members:

Panel 1:
- Eric Metz, California Coastal Commission
- Calvin Fong, U.S. Army Corps of Engineers
- Felix E. Smith, U.S. Fish & Wildlife Service
- Robert Radovich, California Department of Fish and Game

Panel 2:
- Nancy Wakeman, Bay Conservation and Development Commission
- Emy Chan, Association of Bay Area Governments
- Bob Jones, Jones & Stokes Associates
- Martin Cohen, California Coastal Conservancy

Panel 3:
- Michael Wilmar, Bay Conservation and Development Commission
- Fred Roberts, Alameda County Mosquito Abatement District
- Dave D. Smith, Dave D. Smith Associates
- Steven Kaufmann, Deputy Attorney General

Panel 4:
- Phil Williams, Phil Williams Associates
- Thomas Firle, San Diego Unified Port District
- Tom Inouye, State Water Control Board
- Terry Bursztynsky, Association of Bay Area Governments

Panel 5:
- Fran Demgen, Demgen Aquatic Biology
- Tom Harvey, San Jose State University
- John Oliver, Moss Landing Marine Laboratory
- Christopher Onuf, University of California, Santa Barbara

Panel 6:
- Tom Niesen, San Francisco State University
- Paul Springer, Humboldt State University
- Robert Holmes, University of California, Santa Barbara
- Steve Balling, University of California, Berkeley
- Howard Shellhammer, San Jose State University

Panel 7:
- Roger Barnhart, California Cooperative Fisheries Research Unit
- Nona Dennis, Madrone Associates
- James Schooley, California State University, Hayward
- Tom Dickert, University of California, Berkeley
- Margaret Race, Stanford University

An eighth paper entitled "Summary of available technical information on past wetland enhancement and restoration projects" was presented by Michael Josselyn and James Buchholz.

The conference was attended by 225 people. Affiliation of conference attendees was 20% university personnel, 51% government agencies, 14% consulting firms, 6% private individuals, and 7% environmental organization representatives. Following each presentation and panel review, presenters answered questions from the audience.

Contributed posters were shown in the evening. Nineteen posters were presented on various technical aspects of marsh restoration.

The conference proceedings were transcribed, edited, and forwarded to the panel conveners. Their papers were then revised and resubmitted for publication in the proceedings volume, *Wetland Restoration and Enhancement in California*. It represents a major review of the status of wetland restoration in the state and provides a guide to the research and analyses needed to improve the techniques and effectiveness of wetland restoration. The volume will be used by the U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Environmental Protection Agency, California Department of Fish and Game, State Coastal Conservancy, California Coastal Commission, and California Sea Grant College Program.

Table 1

Panel Conveners	Affiliation	Title
Susa Gates	California Coastal Conservancy	An inventory of California wetlands with a potential for restoration and development
John Zentner	California Coastal Commission	Regional goals for wetland restoration in California
Scott McCreary	California Coastal Conservancy	Legal and institutional constraints and opportunities in wetland restoration
Ray Krone	University of California, Davis	Engineering wetlands: circulation, sedimentation, and water quality
Joy Zedler Michael Josselyn	San Diego State University San Francisco State University	Restoration techniques, research, and monitoring: vegetation
Milton Boyd	Humboldt State University	Restoration techniques, research, and monitoring: animals
Jens Sorensen	Jens Sorensen Consulting	Toward an overall strategy in designing wetland restorations

Cooperating Organizations
Bay Conservation and Development Commission
California Coastal Commission
California Coastal Conservancy
California State University, Hayward
San Francisco State University
Tiburon Center for Environmental Studies

Publications

JOSSELYN, M., ED. 1982. Wetland restoration and enhancement in California. Report # T-CSGCP-007. California Sea Grant College Program, La Jolla, California. Proceedings of a workshop held California State University, Hayward, February 1982.

AQUARIUM ENERGETICS AND GROWTH RATES OF *ANOPLOPOMA FIMBRIA*

University of California, San Diego
R/NP-1-10I
1981-1982

G. N. Somero and K. M. Sullivan

Energetics studies of sablefish were initiated to learn more about energy allocation patterns in a wide-ranging, relatively deep-living benthopelagic fish. Sablefish have an extremely broad geographic range along the continental slope from Baja California to the Bering Sea and westward to Japan. The bathymetric distribtion of this fish is equally broad, extending from surface waters in the northernmost areas of its range to a depth of over 1,500 meters off southern California. Throughout its range, the sablefish is fished commercially, although the center of its abundance is off southeast Alaska and its abundance decreases moving from north to south. Off southern California, the extreme southern end of its range, the sablefish is notably smaller and of lower commercial value because of higher water and lower lipid contents of the muscle. It is uncertain whether sablefish successfully spawn south of Point Conception, California. In the laboratory, we wanted to investigate the energetics patterns of sablefish starved and maintained on low ration levels because it has been suggested that sablefish occurring off southern California are smaller due to low food availability at the depths they occur.

This study examined the physiological response of sablefish collected off San Diego, California at a depth of 500 meters to three ration levels: starved, half ration (7% of fish wet-weight per week), and full ration (15% of fish wet-weight per week). The diet consisted of chopped mackerel and squid. Eighteen fish ranging from 0.8-1.95 kg were kept in chilled (6-8°C) seawater tanks for up to 6 months. The summary of growth and ingestion rates is given in table 1.

It has already been noted that sablefish are capable of surviving several months of food deprivation in the laboratory (Sullivan and Smith, 1982). Examining respiration and excretion rates during the course of starvation in this investigation offers insight into the energetic strategies for coping with long-term food deprivation in laboratory-held fish. During the first 9 weeks of starvation, respiration rates were extremely variable during a given 24-hour period, and are comparable to respiration rates of fed fish in postabsorptive condition. Very high oxygen consumption to nitrogen excretion (O:N) ratios are characteristic after several weeks of starvation. This would indicate that the fish is utilizing lipid stores rather than protein as an energy source, accounting for the low nitrogen excretion rates. The highly variable respiration rates could be associated with a response to moving or migrating to increase the chance of the sablefish encountering prey. After 18 weeks of starvation, sablefish respiration rates are lower, and more uniform over a 24-hour period. Nitrogen excretion rates increase, and are comparable to postabsorptive excretion levels in fed fish. The resulting decrease in the O:N ratio suggests that the fish is both conserving energy by lowering metabolic rates and utilizing both protein and lipid stores. Based on this investigation, it appears that sablefish can survive at least 200 days without food under laboratory conditions. This estimate does not take into account the cost of swimming, however, the fish is very inactive after more than 10 weeks of starvation. The change in the respiration patterns of individual starved fish over the course of the experiment is illustrated in figure 1.

The actions taken by sablefish when faced with food deprivation or limited food appear to follow a sequence fairly consistent between individuals. Half-ration fish, with limited food, maintain high lipid stores in the muscle and liver tissue at the expense of losing weight (i.e., shunting energy away from growth). In the case of short-term food deprivation, the sablefish can utilize its lipid stores in both muscle and lipid tissue. With prolonged starvation, the species utilizes both lipid and protein stores, drawing on functional proteins and selected structural proteins in white muscle. Judging from the diel pattern of respiration rates in fed fish at the beginning of the laboratory experiment, sablefish may have a diel activity pattern associated with feeding. Sablefish initially faced with a lack of food may spend a prescribed amount of energy on elevated metabolic rates in order to move and increase the probability of prey encounter. All these actions give the species flexibility to exist on relatively large, infrequent meals or on a seasonally abundant food item. It is not known if key prey items for sablefish off southern Califonia are seasonal in their availability. This flexibility in starvation physiology of the sablefish could account for the success of the species in increasing its bathymetric range, and thus its geographic range at lower latitudes.

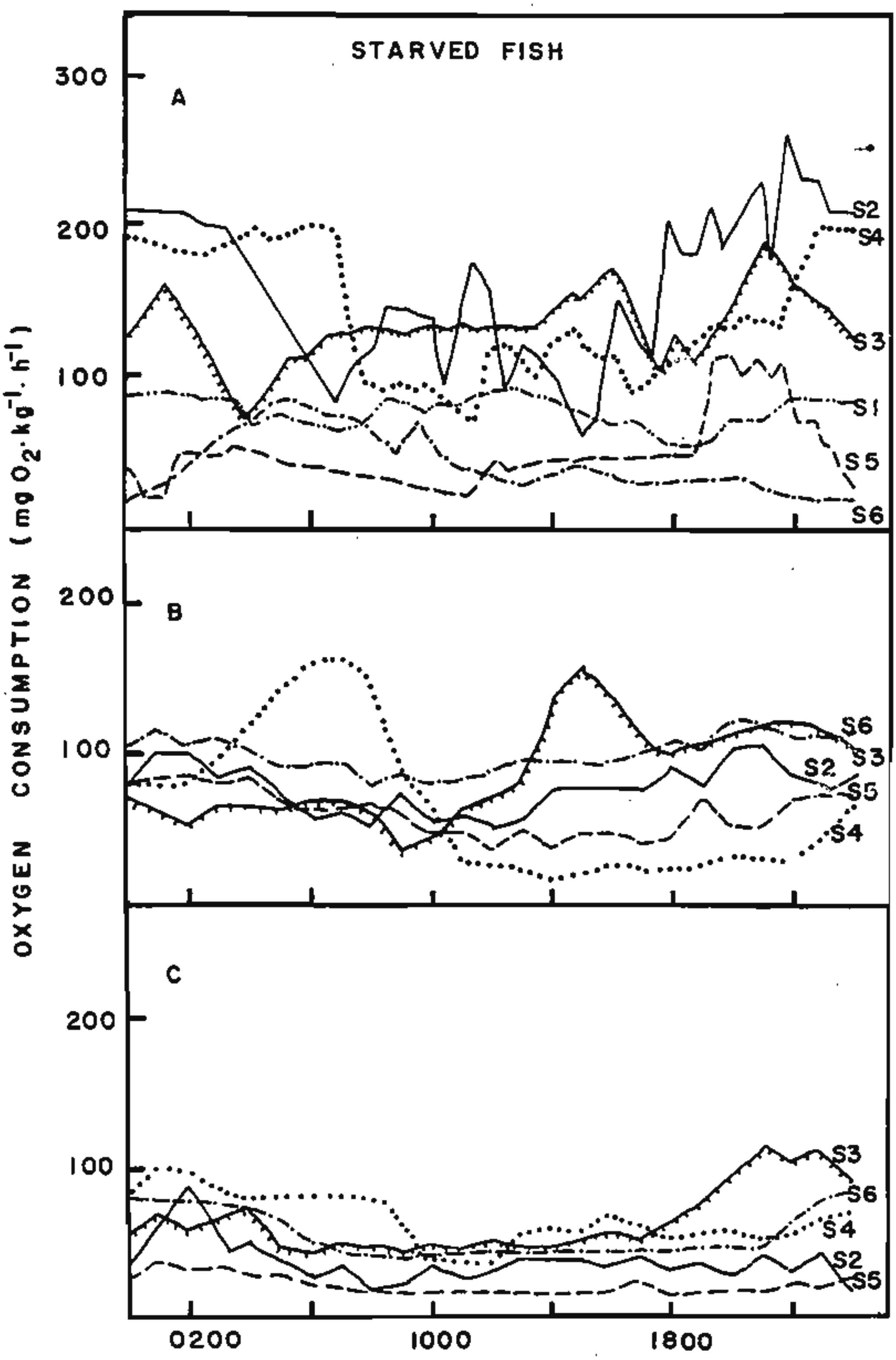


Figure 1. Changes in fish respiration patterns during starvation periods.

Table 1

Growth, Ingestion and Percent Change in Weight for Sablefish *(Anoplopoma fimbria)* Maintained on Three Ration Sizes for up to Six Months (24 Weeks)[1]

Fish # (Sex)	Initial Weight (kg)	Final Weight (kg)	Ingestion (Average g /wk ± S.D.)	Months Observed	% Change in Weight	Kg Change/ Month
Starved						
S1 (F)	1.10	1.00	0	1.2	− 1%	−.008
S2 (M)	0.97	0.76	0	6.0	−22%	−.036
S3 (M)	0.79	0.71	0	6.0	−10%	−.013
S4 (M)	0.97	0.77	0	6.0	−18%	−.029
S5 (F)	1.59	1.37	0	6.0	−14%	−.037
S6 (F)	1.78	1.48	0	6.0	−17%	−.051
Half-ration[2]						
H1 (F)	1.28	1.40	62.3 ± 34	6.0	+ 9%	+.019
H2 (F)	1.30	1.09	14.8 ± 24	4.5	−16%	
H3 (F)	1.99	1.92	78.5 ± 39	6.0	− 4%	−.012
H4 (F)	1.59	1.41	69.7 ± 28	4.0	−11%	−.045
H5 (M)	0.80	1.10	65.2 ± 32	6.0	+37%	+.049
H6 (M)	1.13	0.99	68.4 ± 8	3.0	−12%	−.045
Full-ration[3]						
F1 (F)	1.25	1.40	104.8 ± 79	6.0	+12%	+.025
F2 (F)	0.98	1.10	104.7 ± 64	4.0	+12%	+.030
F3 (F)	1.41	1.87	136.4 ± 87	6.0	+33%	+.077
F4 (F)	1.56	2.24	211.5 ± 80	6.0	+43%	+.113
F5 (F)	0.81	1.27	188.8 ± 62	4.0	+57%	+.115
F6 (F)	1.19	1.60	179.4 ± 83	4.5	+31%	+.082

[1] Fish are grouped into "starved," "half-ration," and "full-ration" treatment groups. Ration size was determined by previous laboratory experiments (Sullivan and Smith, 1982).
[2] (7% of wet body weight per week)
[3] (15% of wet body weight per week)

Cooperating Organizations
Sandia Laboratories

Publications

Sullivan, K. M. Submitted. Changes in respiration, excretion and growth rates of starved and fed sablefish, *Anoplopoma fimbria*. Canadian Journal of Fisheries and Aquatic Sciences.

Sullivan, K. M. and Smith, K. L., Jr. 1982. Energetics of sablefish, *Anoplopoma fimbria*, under laboratory conditions. Canadian Journal of Fisheries and Aquatic Sciences. 39(7).

Sullivan, K. M. and Somero, G. N. In press. Size and diet-related variations in enzymic activity and tissue composition in the sablefish, *Anoplopoma fimbria*. Biological Bulletin.

VEGETATIVE PROPAGATION OF COMMERCIALLY IMPORTANT BENTHIC ALGAE

University of California, Santa Barbara
R/NP-1-11A
1981-82

A. Gibor

We are continuing to grow axenic tissues of *Porphyra*. We originally obtained these tissues (2 years ago) from single cells derived from dispersed vegetative tissues.

A large number of the growing colonies produced masses of cells with a typical "callus" appearance (figure 1). Calluses grew especially at the interface between the air and the soft-agar medium. Whether the semidry environment is conducive to this type of growth has not been established yet. These calluses varied in degree of pigmentation; some were quite red while others appeared colorless. These undifferentiated cell masses were transferred for further growth under a variety of culture conditions. The calluses are relatively brittle; we are attempting to obtain dispersed cell suspensions from them by growing them in liquid with vigorous agitation.

A viable growing cell suspension will be valuable for future studies on obtaining genetic mutations and for studies on the factors that induce these undifferentiated cells to develop into plantlets.

With the aid of a graduate student, Muftah Zarmouh, we are studying the cultivation and breeding of the kelp *Macrocystis*. We isolated axenic cultures of the gametophytes of this plant. We are maintaining separate cultures of male and female gametophytes. We are able to disperse these plants to viable single cells which can be regrown to produce gametophytic colonies (figure 2).

We are now defining the conditions for induction of sexual maturity of these gametophytic plants. We are also determining morphological, physiological, and biochemical parameters by which the male and female plants are distinguishable. Such gametophytic cultures will serve subsequently for the isolation of mutants as well as production of desirable hybrids of these valuable plants.

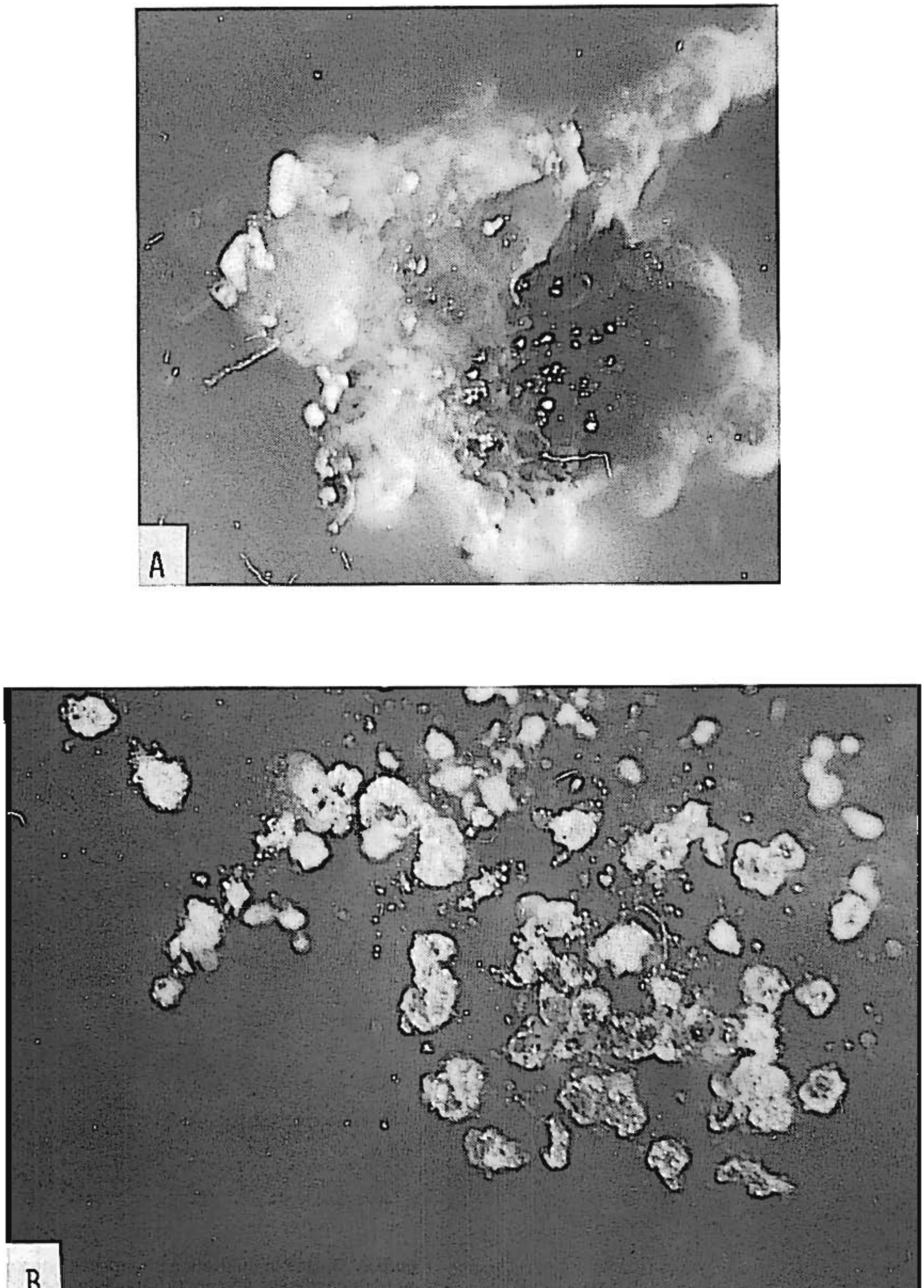


Figure 1. Callus-type growth of axenic *Porphyra* tissue cultivated on semisolid culture medium.
a) Surface view of a culture plate (X12).
b) Closer view of a callus, note several rhizoids growing from the clamp (X200). Portions of the clump were heavily pigmented while others were pale.

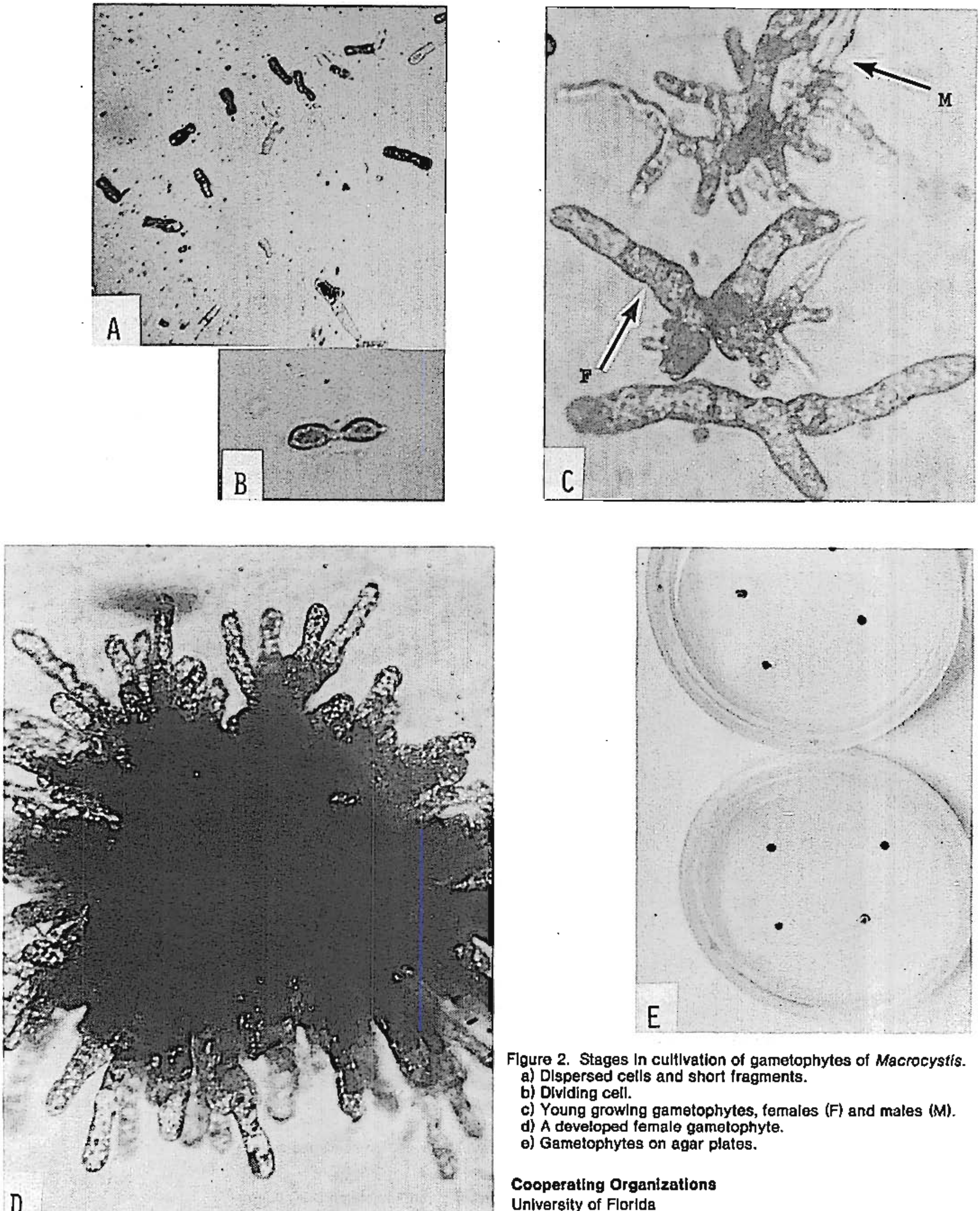


Figure 2. Stages in cultivation of gametophytes of *Macrocystis*.
a) Dispersed cells and short fragments.
b) Dividing cell.
c) Young growing gametophytes, females (F) and males (M).
d) A developed female gametophyte.
e) Gametophytes on agar plates.

Cooperating Organizations
University of Florida
Gas Research Institute

ECONOMIC ANALYSIS OF THE IMPACT OF AQUACULTURE ON COMMERCIAL FISHERIES

University of California, Davis
R/NP-1-11B
1981-82

Warren Johnston and James Wilen

The primary goal of the project, to develop and analyze a series of models that characterize the interactive behavior of commercial aquaculturists and fishermen, is nearly complete. This article summarizes the models and results, all of which are currently being reviewed and refined.

The first model is of an open-access fishery facing market competition from the entry of a purely competitive aquaculturist. This model uses stability analysis of differential equations representing fish population dynamics, demand adjustment, and capital adjustment. The general conclusions are 1) the range where price and quantity will tend to be unstable is reduced, 2) the natural fish population will tend to increase, and 3) the commercial fishery will become more efficient as entry occurs.

The control theory model is utilized to analyze the optimal reaction of a cooperatively managed commercial fishery to shifts in net demand caused by entry of a competing aquaculture supply. The results indicate that if net demand is decreasing, the fishermen should temporarily extract extra profits, taking advantage of the lagged entry of the competitor. If the net demand is increasing, the optimal policy would be to temporarily enter a price war strategy.

The control theory model is again employed to analyze the optimal behavior of a large corporate aquaculturist. Results indicate market power could be used to influence the exit and entry of fishermen by indirectly controlling the supply and stock of natural fish.

The preceding models are expanded to include biological interaction as exists in salmon ranching. Results indicate that when demand is low, the equilibrium supply comes from the natural stocks alone. As demand shifts outward, the equilibrium supply will be both from the aquaculturist and the fishermen who catch both natural and aquacultured fish. Finally, when demand shifts further, the natural stock may be destroyed by overfishing or competition from aquacultured stock. The range of demands under which both natural and aquacultured stock exist is sensitive to fisheries policies which result in changes in effort or natural stocks. Another conclusion of this model is that there are theoretical cases where a large aquaculturist may wish to drive the natural stocks to zero, thereby gaining relatively more control.

The second goal of applying these models to case studies of salmon ranching and the potential developments in the lobster industry is still in progress. Results are not yet available.

Cooperating Organizations
California Department of Fish and Game
Oregon Department of Fish and Wildlife
Oregon State University
Pacific Fisheries Management Council
University of California, Davis
Washington Department of Fisheries

AGE AND GROWTH OF PELAGIC SHARKS: MANAGEMENT INFORMATION FOR CALIFORNIA'S EMERGING FISHERIES

Moss Landing Marine Laboratories/
San Jose State University
R/NP-1-11C
1981-82

Gregor M. Cailliet

Commercial fishing for elasmobranchs is increasing at a tremendous rate in California. Three pelagic species have comprised the majority of the catch. Blue shark (*Prionace glauca*) landings in San Pedro, California, have increased from virtually nothing in 1978 to over 188,000 pounds in 1980. Similar trends have occurred for common thresher (*Alopias vulpinus*) and shortfin mako (*Isurus oxyrinchus*) sharks. Landings of common thresher and shortfin mako increased from 15,500 pounds and 1129 pounds in 1978 to 994,000 pounds and 62,000 pounds, respectively, in 1980.

A major problem with this increased commercial use is the lack of life-history information necessary for effective management. For example, age determination has not been evaluated sufficiently for the majority of elasmobranchs in California, and therefore, such critical information as age at first maturity is not known. Therefore, the objectives of this project were to use recently developed techniques to enhance growth bands on centra for these three west coast pelagic sharks, make estimates of age based on counts of these structures, and construct preliminary growth curves. Finally, because these pelagic sharks appear to range widely over the oceans (Strasburg, 1958), very little information has been gathered that could verify the annual nature of bands in their vertebral centra. We attempted to use what little information was available on their size and reproduction to evaluate our growth curves.

We obtained specimens of these three species from our own fishing activities and from commercial fishermen, the California Department of Fish and Game, and various California museums. Sharks were measured and weighed and their sex and reproductive status noted, if possible. For age determination, a section of the vertebral column was removed, usually just anterior to the first dorsal fin, or from the caudal region of previously cleaned market specimens. For all three species, several individual vertebra were cleaned using a combination of steps. The aging technique used for blue sharks was silver nitrate impregnation, while x-radiography was used on common thresher and shortfin mako sharks.

For both of these techniques, procedures for counting the concentric lines were standardized. We defined any concentric line found on a centrum a "ring." We further defined "band" as a group of rings. Two kinds of bands occurred, those which appeared transparent with transmitted light, and those which were more opaque. We assumed that opaque bands were more heavily mineralized and represented summer growth on the centrum (see Jones and Geen, 1977). To ensure the accuracy of band counts, at least two observers made independent replicate counts of the most opaque bands on each centrum.

For simplicity and the widest applicability of this preliminary age information, we fit our data on age and length for all three species to the von Bertalanffy growth equation. Growth was characterized for all three species by plotting individual total length (TL) values against estimated ages, and by plotting the predicted von Bertalanffy growth curve based upon the parameters L_∞, k, and t_0 for combined sexes. For the shortfin mako, we also used the logistic growth equation.

Blue Shark

We caught a total of 120 blue sharks between 1974 and 1977, with an additional 42 specimens coming from museum collections and the commercial catch in southern California taken over a wider range of years.

Based on counts of 130 silver nitrate-treated centra, the von Bertalanffy growth curve for blue sharks aged, which ranged between 280 and 2521 mm TL, rose steeply and leveled at an estimated TL of 2655 mm for both sexes combined (figure 1). The oldest fish in our sample was a 2450 mm TL male that had 9 bands, while the youngest were two near-term embryos that had no bands and were between 350 and 400 mm TL. The male asymptotic length was close to that of the largest common specimens collected in the Pacific (around 3100 mm TL, Strasburg, 1958), but was considerably smaller than the largest reported blue shark (3962 mm TL; Bigelow and Schroeder, 1948). Extrapolating from our growth curve for combined sexes using the von Bertalanffy equation, a fish at the asymptotic length of 2655 mm TL would be approximately 20 years old.

Our estimate of size at birth (435 mm TL), derived from the von Bertalanffy growth curve, was situated between the reported sizes of free-living young (340 and 530 mm TL; Bigelow and Schroeder, 1948; Tucker and Newnham, 1957; Strasburg, 1958; Hart, 1973; and Pratt, 1979). Our growth curve corresponds to that of Stevens (1975, 1976), up to about 2000 mm TL. The differences between these two studies could be due in part to the methods used to calculate the von Bertalanffy growth parameters. Of course, blue sharks living under different oceanic conditions could exhibit different growth characteristics. According to Pratt (1979), the blue shark reaches maturity at approximately 2200 mm TL, which, according to our age estimates, is 6 or 7 years of age. Thus, blue sharks become reproductively mature at about 56% of their maximum reported size, 83% of their estimated asymptotic length, and 30% of their estimated maximum age.

Thresher Shark

A total of 167 thresher sharks was collected from the southern California gill net fishery and museum collections. The x-radiography technique was chosen to age thresher sharks, because it worked consistently well and easily processed many vertebrae in a short time. The von Bertalanffy growth curve for the 143 common thresher sharks aged, which ranged between 360 and 5733 mm TL, rose gradually and began to level toward the estimated asymptotic length (L_∞) of 6509 for both sexes combined (figure 2). The two oldest fish aged had 15 bands and measured 5102 and 5389 mm TL, and the youngest were eight embryos ranging between 360 and 1605 mm TL, having no bands.

The combined asymptotic length from the von Bertalanffy growth curve was 6509 mm TL, which is only 14% smaller than the maximum reported length of 7600 mm TL, and within the size range of the commonly occurring largest specimens collected in the Pacific (Strasburg, 1958; Hart, 1973). Using our growth curve, a fish at the asymptotic length of 6509 mm TL would be close to 50 years old.

Our estimate of size at birth, derived from the von Bertalanffy growth model (1580 mm TL) is slightly higher than reported smaller sizes of free-living young, which can be as small as 1168 mm TL (Bigelow and Schroeder, 1948) and range up to about 1500 mm TL (Hixon, 1979). Common thresher shark females range in length from 2600 to 4267 mm TL (Bigelow and Schroeder, 1948; Strasburg, 1958; and Gubanov, 1978). These lengths at first maturity represent sharks ranging from 3 to 7 years old (figure 2). Using our asymptotic length of 6509 mm TL, common threshers apparently mature at a size which is between 39 and 66% of this length. However, if we use the maximum reported size of 7600 mm TL, these sharks mature at between 34 and 56% of their maximum length. Using age at first maturity versus projected oldest age, the figures would be much lower, reaching maturity at between 6 and 14% of their lifespan. More observations on older and larger sharks need to be made.

Shortfin Mako

Fewer specimens (50) of the shortfin mako shark were available from the commercial catches between 1978 and 1982 and museum collections, the smallest being a free-living 900 mm TL male, and the largest a 3210 mm TL female.

The x-radiography technique was used to age shortfin mako sharks in this study. The von Bertalanffy growth curve for the 44 shortfin mako sharks we aged demonstrates a relatively slow growth rate which levels off at an asymptotic length of only 3210 mm TL (figure 3). The oldest fish was estimated to have 17 bands and was our largest specimen, measuring 3210 mm TL, exactly the same length as our estimated asymptotic length. The estimated asymptotic length is only 9% less than the maximum California reported length of 3507 mm TL (Applegate, 1977), but is 16% less than the largest Indian Ocean specimen, measuring 3800 mm TL, (Gubanov, 1974), and 19% less than the maximum world size of 3962 mm TL (Bigelow and Schroeder, 1948; Roedel and Ripley, 1950; and Miller and Lea, 1972). Using the logistic growth equation on the same data produces a different curve and a more reasonable estimate of asymptotic length of 4081 mm TL (figure 3), which is only 3% higher than the reported maximum sizes worldwide.

Our estimates of size at birth, derived from either the von Bertalanffy or the logistic growth curves, agree with the scanty information available about the smallest, free-living shortfin mako sharks (Strasburg, 1958; Garrick, 1967; and Gubanov, 1978). Extrapolating the age at which these sharks reach asymptotic lengths estimates longevity to be about 45 years, based upon both growth models.

Shortfin mako sharks reportedly do not mature until they reach a length of 1800 mm TL (Gubanov, 1978) to 1828 mm TL (Bigelow and Schroeder, 1948), which corresponds to an age of about 7 to 8 years (figure 3). Thus, shortfin makos reach first maturity at a size which is only 56 to 57%, or 44 to 45% of the asymptotic lengths estimated by the von Bertalanffy and logistic growth models, respectively. They reach first maturity at a size which is only 51% of the maximum length reported off California, and 45% of the maximum world size. Using age at first maturity and the predicted age at which asymptotic length is reached (45 years), the figures would be much lower, with the sharks reaching maturity at between 15.5 and 17.8% of their lifespan.

In conclusion, our preliminary data and the available literature indicate that these three pelagic sharks attain large sizes and exhibit relatively slow growth rates, long lifespans, and relatively low but variable fecundities. Therefore, as first postulated by Holden (1973, 1974, 1977), it is quite possible that this combination of life history traits could make these species susceptible to overfishing, depending upon their population abundance, distribution, and migration patterns. However, this conclusion may be countered by our estimate of a relatively early age of first reproductive maturity. More extensive samples of all sizes over a wider geographical range, an equal representation of sexes, and more detailed analysis of age, growth, and reproduction need to be conducted before definitive statements can be made about the life histories of these species. Only then will be be able to accurately predict the future of these fisheries, and perhaps satisfactorily manage them.

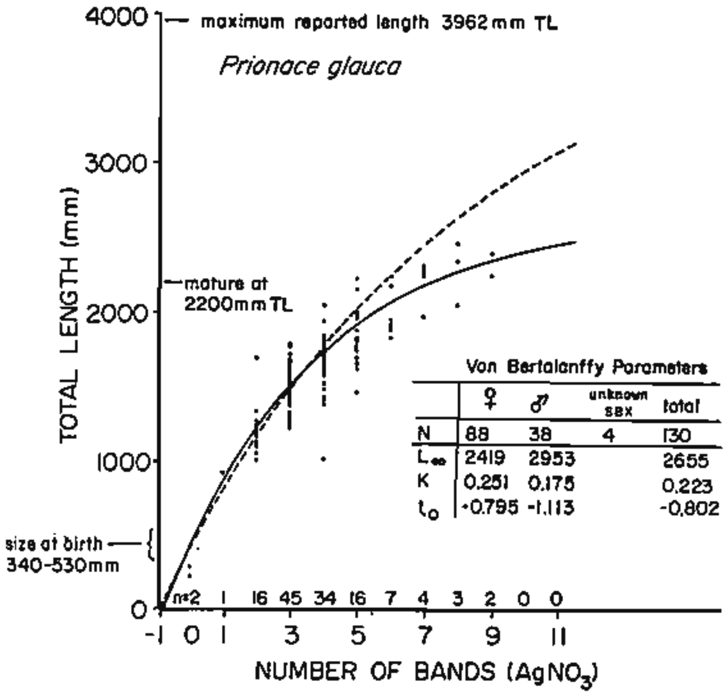


Figure 1. Von Bertalanffy growth curve for 130 blue sharks collected in California waters where age was estimated using silver nitrate. Dots represent individuals of both sexes, and von Bertalanffy parameters for males, females, and the total sample are given in the insert. Dashed growth curve is based on Stevens (1975) and references used for size at birth, size at maturity, and maximum size were Bigelow and Schroeder (1948), Strasburg (1958), Hart (1973), Gubanov (1978), and Pratt (1979).

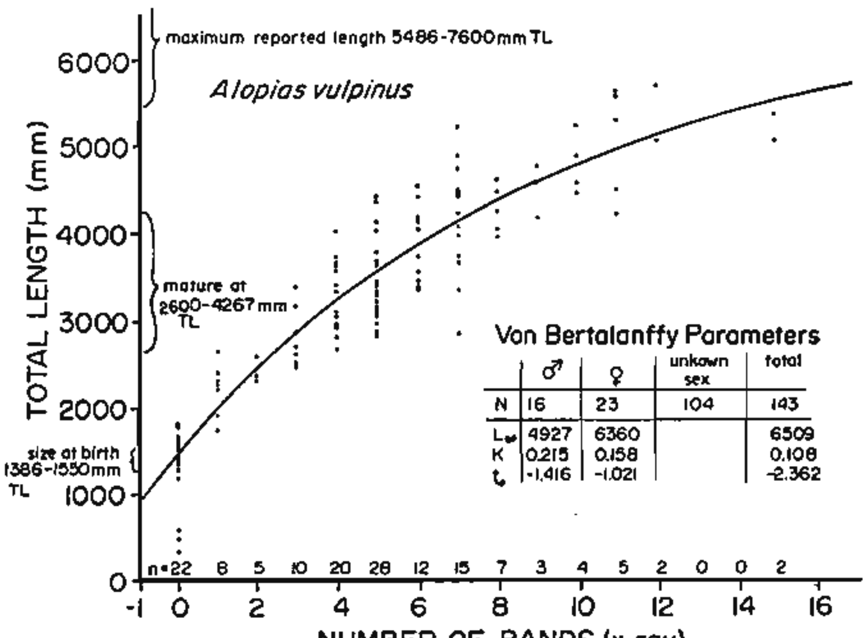


Figure 2. Von Bertalanffy growth curve for 143 common thresher sharks collected in California waters and aged using x-radiography. Dots represent individuals of both sexes, and von Bertalanffy parameters for males, females, and the total sample are given in the insert. References used for size at birth, size at maturity, and maximum reported size were Bigelow and Schroeder (1948), Roedel and Ripley (1950), Miller and Lea (1972), Hart (1973), Gubanov (1978), Hixon (1979), and D. Bedford, California Department of fish and Game, pers. comm.

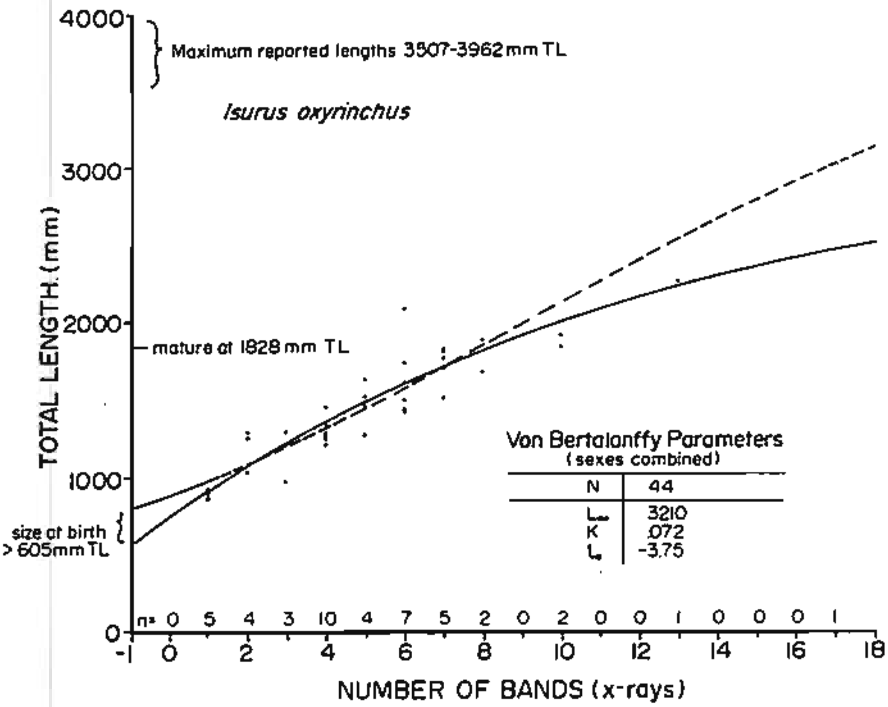


Figure 3. Von Bertalanffy (solid line) and logistic (dashed line) growth curves for 44 shortfin mako sharks collected in California waters which were aged using x-radiography. Sexes were combined due to small sample size, and von Bertalanffy parameters are for all 44 specimens. Reported size at birth, size at first maturity, and maximum size are from Bigelow and Schroeder (1948), Roedel and Ripley (1950), Garrick (1967), Applegate (1977), and Gubanov (1978).

Cooperating Organizations
Cabrillo Museum
California Academy of Sciences
California Department of Fish and Game
California Gillnetters Association
Chesapeake Fish Company
Commercial Fishermen of Santa Barbara
Fisherman's Market, Santa Barbara
Los Angeles County Museum of Natural History
Santa Barbara Museum of Natural History
Sea Grant Area Marine Advisors in San Diego, Los Angeles, Santa Barbara, and Monterey
Sea World, San Diego
Seafood Specialties, Santa Barbara
Tiburon Center for Environmental Studies
United Fishermen's Organization, L.A.

References

APPLEGATE, S. P. 1967. A survey of shark hard parts. In *Sharks skates and rays*, D. W. Gilbert, R. F. Mathewson, and D. P. Rall, eds. Johns Hopkins Press, Maryland.

APPLEGATE, S. P. 1977. A new record-size bonito shark, *Isurus oxyrinchus* Rafinesque, from southern California. Calif. Fish and Game 63(2):126-129.

BIGELOW, H. B. AND SHROEDER, W. C. 1948. Fishes of the western north Atlantic. Mem. Sears Found. for Mar. Res. 1:282-292.

GARRICK, J. A. F. 1967. Revision of sharks of genus *Isurus* with description of a new species (*Galeoidea, Lamnidae*). Proc., U.S. Nat. Mus. 118(3537):663-690.

GUBANOV, Y. P. 1974. The capture of a giant specimen of the mako shark *Isurus glaucus* in the Indian Ocean. J. Ichthyology 14(4):589-591.

GUBANOV, Y. P. 1978. The reproduction of some species of pelagic sharks from the equatorial zone of the Indian Ocean. J. Ichthyology 18(5):781-792.

HART, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can. Bull. 180:1-740.

HIXON, M. A. Term fetuses from a large common thresher shark, *Alopias vulpinus*. Calif. Fish and Game 65(3):191-192.

HOLDEN, M. J. 1973. Are long-term sustainable fisheries for elasmobranchs possible? J. du Conseil, Rapports et Proces-Verbaux Reun. Cons. Int. Explor. Mer. 164:360-367.

HOLDEN, M. J. 1974. Problems in the rational exploitation of elasmobranch populations and some suggested solutions. In *Sea Fisheries Research*, F. R. Harden-Jones, ed. John Wiley and Sons, New York.

HOLDEN, M. J. 1977. Elasmobranchs. In *Fish Population Dynamics*, J. A. Gulland, ed. John Wiley and Sons, New York.
JONES, B. C. AND GEEN, G. H. 1977a. Age determination of an elasmobranch (*Squalus acanthias*) by X-ray spectrometry. J. Fish Res. Board Can. 34:44-48.
MILLER, D. J. AND LEA, R. N. 1972. Guide to the coastal marine fishes of California. Calif. Fish and Game Fish Bull. 157:1-249.
PRATT, H. L. 1979. Reproduction in the blue shark, *Prionace glauca*. Fishery Bull. 77(2):445-470.
ROEDEL, P. M. AND RIPLEY, W. E. 1950. California sharks and rays. Calif. Dept. Fish and Game Fish Bull. 75:1-88.
STEVENS, J. D. 1975. Vertebral rings as a means of age determination in the blue shark (*Prionace glauca* L.). J. Mar. Biol. Assoc. U.K. 55:657-665.
STEVENS, J. D. 1976. First results of shark tagging in the northeast Atlantic, 1972-1975. J. Mar. Biol. Assoc. U.K. 56:929-937.
STRASBURG, D. W. 1958. Distribution, abundance, and habits of pelagic sharks in the central Pacific ocean. Fishery Bull. 138(58):335-361.
TUCKER, D. W. AND NEWNHAM, C. T. 1957. The blue shark *Prionace glauca* (L.) breeds in British seas. Ser. 12. 10:673-688. Am. Mus. Nat. Hist.

Publications

CAILLIET, G. M., MARTIN, L. K., HARVEY, J. T., KUSHER, D., AND WELDEN, B. In press. Preliminary studies on the age and growth of blue (*Prionace glauca*), common thresher (*Allopas vulpinus*), and shortfin mako (*Isurus oxyrinchus*) sharks from California waters. In *Proceedings, International workshop on age determination of oceanic pelagic fishes — tunas, billfishes, sharks*, E. D. Prince and L. M. Pulos, eds. NMFS Fisheries Circular.
CAILLIET, G. M., MARTIN, L. K., KUSHER, D., WOLF, P., AND WELDEN, B. In press. Techniques for enhancing vertebral bands in age estimation of California elasmobranchs. In *Proceedings, International workshop on age determination of oceanic pelagic fishes — tunas, billfishes, sharks*, E. D. Prince and L. M. Pulos, eds. NMFS Fisheries Circular.

THE DISTRIBUTION AND INTERPRETATION OF THE 1980 CIF MODEL AND THE REFINEMENT OF USER-ORIENTED COMPUTER PROGRAMS

San Diego State University
R/NP-1-11D
1981-82

Dennis M. King

Research conducted during 1980-81 under this Sea Grant project resulted in a fishery-related, input-output model of the 1980 California economy. The response to the Sea Grant survey conducted as part of that research was better than expected; at the end of that project there were approximately 80 returned questionnaires labeled "other fishing activities" which could not be processed within the scope of the original study. A review of these questionnaires indicated that, with a small amount of additional work, these questionnaires could be used to specify between two and five additional fish harvesting sectors in the CIF model. This project was developed to adapt those questionnaires to the model, respecify the model to accomodate new information, and assist users of the CIF model as they addressed various fishery management problems.

Approach

The general approach was to sort the questionnaires into logical categories, analyze them, and merge them where appropriate with the 19 fish harvesting sectors already specified in the CIF model. The processing of the additional questionnaires resulted in the respecification of the original diveboat sector into two separate sectors (sea urchin and abalone) and the specification of a new rod and reel sector in the CIF model. These changes required some corresponding changes in text and tables contained in the Sea Grant reports describing the CIF model and in the computer programs used to run the CIF model. Since coefficients, multipliers, etc. for all fishing sectors changed slightly as a result of the modifications, all tables contained in the original report were modified slightly.

Results

The revised CIF model has 21 fish harvesting sectors instead of the original 19 but is otherwise identical to the model described in the 1980-81 reports. All of the fishery-related coefficients changed slightly with the inclusion of the new sectors but not enough to cause problems for current users of the original model. The revised model has more detail and is more precise than the original model, but since the original is still reliable and additional changes are expected during 1983, no attempt was made to distribute the revised model to all users. Current revisions and those to be made during the 1983 project will be incorporated into a single publication at the end of the 1983 project.

Copies of the revised CIF model with tables and charts showing revised multipliers and "make" and "use" tables are available at the Center for Marine Studies, San Diego State University.

Cooperating Organizations

California Division of Fish and Game
California Seafood Institute
National Marine Fisheries Service
Pacific Coast Federation of Fishermen's Associations

REORGANIZING AND UPDATING AN ADVANCED COURSE IN MARINE POLICY

University of California, San Diego
R/NP-1-11E
1981-82

Roger Revelle

During the spring quarter of the 1979-80 academic year, a prototype course in marine policy was offered for the first time at the University of California, San Diego (UCSD). The organization of this course was funded through Sea Grant project # R/NP-1-8D. Jens Sorensen, the project leader, organized a theoretical and factual framework of lectures based on a perceived set of contemporary marine policy issues.

The course was initially offered in a lecture format. Response to the course was excellent and demand for the course during the 1980-81 academic year was very high. Unfortunately, administrative changes did not permit the course to be offered that year.

Interest in the subject matter survived well through that year and was prevalent during the fall quarter of the 1981-82 academic year. On that basis it was the mutual decision of Professor Revelle and the Department of Political Science that the course should be offered during spring quarter of this new year.

The initial task, or objective, was to begin organizing a seminar course around the most current and relevant marine policy issues. A brief look at the organization of topics for the 1980 prototype course indicated that a completely new approach was necessary. In 2 years, the entire spectrum of marine policy issues and their emphases had been completely altered. Those issues of greatest national concern were quickly becoming more and more international in character. Subsequently, the seminar took on a more international approach. For example, many weekly seminar topics were introduced in relation to the Third United Nations Conference on the Law of the Sea.

Our second aim was to establish a network of cooperative communication between every major U.S. university offering marine policy courses. We identified 10 universities or institutions where similar instruction was currently taking place. We mailed an outline of the weekly topics, their corresponding reading lists, and a request for feedback as well as their course information and/or materials. We received just such feedback and course descriptions from nearly every one of these institutions as well as the understanding that institutions within this network would maintain contact with respect to future course offerings or changes.

Cooperating Organizations

Inter-American Tropical Tuna Commission

Publications

Molitor, M. 1982. The U.S. deep seabed mining regulations: the legal basis for an alternative regime. San Diego Law Review 19(2).

THE EFFECTS OF ENVIRONMENTAL FACTORS ON THE ABILITY OF CHEMICAL CUES TO TRIGGER SETTLEMENT AND METAMORPHOSES OF BIVALVE LARVAE

Humboldt State University
R/NP-1-11F
1981-82

William N. Shaw

Simple chemical compounds have been shown to trigger attachment and metamorphosis of the larvae of several species of marine invertebrates. The simplest molecules with which settlement-inducing activity has been demonstrated are L-3,4-dihydroxyphenylalanine (DOPA), gamma-aminobutyric acid (GABA), and choline. These molecules occur in the marine environment covalently bound to compounds associated with adhesives, lubricants, exoskeletal proteins, and pigments.

A review of numerous studies clearly implicates these chemical cues in successful habitat selection by the larvae at the termination of the planktonic stage of the life cycle. The similarity between these molecules and neurotransmitters suggests that the chemoreceptors are modified either ontogenetically or phylogenetically from receptors specific to the neurotransmitters dopamine, GABA, and acetylcholine. Selectivity in response by a larvae to a given chemical appears to depend on the neurotransmitter-like portion of the compound, whereas specificity appears to depend on the protein, carbohydrate, or lipid constituents.

Pediveligers of the mussel *Mytilus edulis* and the oyster *Crassostrea gigas* settle in response to the amino acid DOPA. Implementing the use of chemicals to commercial setting systems depends on being able to either modify the chemoreceptors so that they respond to an inexpensive and easily available chemical and/or manipulating settlement behaviors. The initial objective of this study is to determine the response of oyster larvae to DOPA, examine the potential for application to existing commercial setting systems, and examine the effect of several environmental factors on the degree of response.

Aliquots of hatchery-reared *C. gigas* pediveligers were tested for attachment in culture dishes to both aged oyster shell and the smooth glass surface of the culture dish. The oyster pediveligers were reared at 34 ppt and at 25°C. Within individual tests the settlement response by the pediveligers was examined following exposure to DOPA at 0.00001 M while varying the salinity (25-35 ppt) and temperature 20-30°C. Controls were run without the addition of DOPA. The results presented are preliminary findings and only indicate observed trends.

In tests that offer only a smooth glass surface for settlement, attachment of the larvae to the glass occurred after 24 hours with, but not without, DOPA being added to the seawater. In the tests to which DOPA was added the highest percentage of attachment occurred at a salinity and temperature combination of 35 ppt at 30°C. The pediveligers also attached to the glass surface at the following salinity and temperature combinations listed in order of decreasing percentage response: 35 ppt at 25°C, 35 ppt at 20°C, and 30 ppt at 30°C. After 48 hours, a relatively high number of pediveligers attached to the glass surface in the runs without DOPA at a salinity and temperature combination of 35 ppt and 30°C. Also at 35 ppt 30°C in the runs with DOPA a smaller yet significant percentage of the pediveligers metamorphosed (indicated by new shell growth) without attaching to the glass surface. This did not occur in any of the other runs.

The oyster pediveligers were next tested for attachment to aged oyster shell in response to the addition of DOPA. Preliminary results indicate that there is a slightly greater set after 24 hours onto the shells in the tests with DOPA. However, exposure of the larvae to DOPA also promotes attachment to the glass surfaces of the culture dishes. The consequence is that after 48 hours the set onto the shell is greater in the runs without DOPA, although total percentage of larvae that undergo metamorphosis appears to be the same. In the runs with DOPA a significant percentage of the larvae either attach to the glass surface or metamorphose without attaching to any substrate.

A greater percentage of larvae metamorphose and/or attach to a substrate when kept under conditions of constant light than under constant darkness. There appears to be no clear correlation between either an increase or decrease in response by the eyed oyster pediveligers within the age range examined.

These findings suggest that DOPA will not increase the percentage of set onto oyster shells when the setting is allowed to occur over several days. Rather, these findings clearly suggest that the use of DOPA promotes extraneous setting onto otherwise unfavorable substrates. However, these findings do not discount the possibility that chemicals can be used to obtain a more rapid set. The use of chemical cues appears to be more applicable to setting systems in which no preferred setting substrate is used, such as in the case of the setting of clams and cultchless oysters.

Cooperating Organizations
Coast Oyster Company, Eureka

CONTROL OF EGG DROP IN THE LOBSTER, *HOMARUS AMERICANUS*

University of California, Riverside
Bodega Marine Laboratory
R/NP-1-11G
1981-82

Prudence Talbot and Dennis Hedgecock

Our project had two major goals: 1) to determine if sperm production in laboratory-maintained male lobsters is seasonal, and 2) to develop a treatment to eliminate or control proliferation of bacteria on the surface with the egg coat and stalk. The latter goal was started but emphasis was placed on determining how frequently epibiotic bacteria caused egg drop.

Twenty-two male lobsters were shipped to the Bodega Marine Laboratory (BML) where they are now permanently housed. Sixteen of these males are still alive and healthy. These are tested for spermatophore extrusion every 2 weeks. Spermatophores are placed in a lobster sperm bank at the BML. These males will be maintained and sampled indefinitely.

Our immediate goal was to establish an experimental male population at BML. This has been accomplished. Our long-term goal is to continue spermatophore collection over a 1-year period. This will establish if spermatophores are produced continually or seasonally. Second, the collected spermatophores will be banked and used to artificially inseminate freshly molted females. The latter project will require several years to complete. Tables 1 and 2 summarize data on spermatophores collected at the Bodega Marine Laboratory.

Preliminary work on regulating the number of bacteria on egg surfaces was begun by Renee Harper. Several antibiotics were found to arrest growth of egg coat bacteria, and a series of bacteriostatic reagents were also tested using an innovative system developed by Renee Harper. Most effort, however, was spent on examining the morphological types of bacteria on egg coats from five different groups of *Homarus*. The number of bacteria on egg coats was also correlated with egg drop-off to determine if the two events are related.

Our results show that eggs and their stalks may have at least four morphological types of bacteria on their surfaces. These bacteria appear on the coats several days after spawning, and reach maximum numbers by 10-24 days after spawning. Wild females as well as lab-maintained females had epibiotic bacteria on their eggs. *H. gammarus* females had fewer total bacteria on their eggs than *H. americanus* females. Also *H. gammarus* coats never had the filamentous *Leucotrix* type bacteria unless the eggs were collected from the tank bottom. Hybrid females (*H. gammarus* x *H. americanus*) resembled *H. americanus* in types and numbers of epibiotic bacteria.

Some females dropped eggs before epibiotic bacteria had an opportunity to flourish, and some females retained eggs even though populated by large numbers of epibiotic bacteria. Most females, however, dropped eggs as the number of bacteria on them increased. We think that some egg coat material is of inferior quality and is more susceptible to bacterial growth than are normal coats. This point requires further investigation.

Table 1[a]

Mean Length (mm) of Spermatophores Collected from *H. americanus* at Bodega Marine Laboratory

Date	Spermatophore Length (mm) ± S.E.	#N[b]
3/18/82	9.1 ± 2.0	20
6/10/82	16.7 ± 2.0	16
6/26/82	23.2 ± 3.1	13
7/14/82	17.6 ± 3.1	13
7/28/82	15.4 ± 4.9	11
9/16/82	18.9 ± 3.1	13
10/26/82	13.5 ± 2.4	13

[a] These data show that spermatophores can be collected from laboratory-maintained males between March and October. As yet there is no clear evidence that spermatophore production is seasonal.
[b] #N = number of mates

Table 2

Mean Length of Spermatophores Reported for Individual Males[a]

Male	#N[b]	Spermatophore Length (mm) ± S.E.
1	6	22.3 ± 5.9
5	7	16.0 ± 2.5
6	6	19.0 ± 6.1
7	6	21.3 ± 6.3
9	6	16.2 ± 8.7
11	7	26.1 ± 3.8
12	7	13.9 ± 4.3
13	7	11.7 ± 3.4
14	6	11.1 ± 3.4
15	6	21.5 ± 2.7
16	7	23.0 ± 2.2
17	5	19.6 ± 5.1
18	6	13.8 ± 4.7
19	7	5.9 ± 3.6
20	6	8.7 ± 2.7

[a] When data are examined for individual males, it is evident that the length of the spermatophores varies considerably from male to male. Male #11 consistently produced large spermatophores of good quality, while male #19 produced either no spermatophores or small, poor quality spermatophores. In aquaculture facilities, it would be advisable to cull males producing poor quality spermatophores from the breeding population.
[b] #N - number of trials

Cooperating Organizations
Aquaculture Enterprises, Monterey
Aquaculture Enterprises, Oxnard

EXPLORING CONFLICTS BETWEEN OFFSHORE OIL DEVELOPMENT AND COMMERCIAL FISHING IN CALIFORNIA

University of California, Santa Barbara
R/NP-1-11H
1981-82

Dean E. Mann

Interactions between the commercial fisheries and offshore hydrocarbon resources development have become increasingly conflicting in California, where intensive exploration of outer continental shelf and state tidelands is taking place. In the near future, conflicts can be expected to intensify, because of major oil and gas discoveries in the Santa Barbara Channel and in the Santa Maria Basin, which are both historical and current areas of valuable commercial fisheries resources.

Our preliminary findings reveal five major sources of conflict between the oil and gas industry and the commercial fisheries. Essentially, all of these conflicts involve disputes over the interference of oil activities with ongoing fisheries exploitation.

The first interaction, and the one that has received the most attention, concerns damage caused to fixed fishing gear such as crab and lobster traps by vessels conducting geophysical surveys. In a number of cases, expensive traps have been lost when seismic survey vessels cut loose the mooring lines holding them in place. Another interaction, again related to the exploratory phase of oil development, concerns exploratory drillships that disrupt trawl fishing grounds and prevent fishing access to them. In areas near Point Conception in particular, fishermen from Port San Luis and Morro Bay have suffered declines in catch because of the interference posed by drillships and associated anchor systems and buoys.

The third interaction concerns mud mounds left when pipelines are set between offshore production platforms and shore-based facilities. Large furrows left by barges when the pipelines are put into place have disrupted fishery resources, and when trawlers pass gear over these areas, they suffer damage to their expensive nets and other equipment.

Thus far, fixed platforms themselves have posed minor problems of access to fishermen. In the future, however, as more platforms are put into place for developing offshore fields, fishermen may lose access to preferred fishing grounds. Conflicts over vessel traffic in the Santa Barbara Channel may also become increasingly severe, given a projected increase in the number of oil supply and crew boats, as well as in the amount of oil tanker activity.

Our research results have revealed that conflicts between the oil and fishing industries have been addressed at the regional level through a variety of information-sharing and coordination efforts. While the actual effectiveness of these measures is impossible to determine precisely at this time, one major finding has been that the intervention of a neutral third party plays an important role in ameliorating conflict. A third party familiar with the sources of conflict, who has the confidence of the various parties involved, can aid immeasurably in forestalling an intensification of hostilities.

For example, John Richards, the Cooperative Extension Sea Grant Marine Advisor, has played a vital role in catalyzing coordination mechanisms between fishing and oil interests. Richards has been a major force acting to prevent interactions from escalating into an increasingly hostile and contentious situation. He has acted as mediator between the two industries by arranging meetings where involved parties could present their perspectives on actual, as well as potential, conflict. He has also educated the fishing community as to which state and federal agencies would be most appropriate for registering complaints and for seeking mitigation measures. Particularly in the context of seismic vessel, exploratory drilling, and pipeline-related conflicts, Richards has actively sought to forestall an intensification of hostilities. Representatives of many of the involved agencies, oil companies, and fishing interests have told us that "without Richards' intervention, the situation would be much worse" than is currently the case.

Our findings at this time reveal also that state and federal agencies' personnel (in the State Lands Commission and Minerals Management Service, respectively) are cautiously optimistic about recent information-sharing initiatives between oil and fishing interests. In the seismic survey vessel situation, for example, vessel operators must now notify fishermen up to 2 weeks before surveys commence, in order that fixed-gear fishermen may remove their gear from the survey area. Again, Richards has been instrumental in seeing that information reaches the fishing community in a timely fashion. Currently, all of those involved are taking a "wait and see" attitude regarding the effectiveness of the new information-sharing and coordination system.

In conclusion, it must be noted that conflicts between oil activities and commercial fisheries will exist for some time to come. With the expected increase in offshore oil activity, commercial fishermen will suffer increasing disruptions of their own activities. Thus, a means for mitigating impacts on fisheries and for minimizing conflict between the various interests will grow in importance. It is our feeling at this time that creative solutions to these conflicts will require a great deal of coordination and planning on the part of the fishing and oil industries, as well as by local, state, and federal planners.

Cooperating Organizations
Atlantic Richfield Corporation
California Coastal Commission
California State Lands Commission
Chevron Corporation
Minerals Management Service of the Bureau of Land Management
San Luis Obispo Board of Supervisors
Santa Barbara Board of Supervisors

Publications
CICIN-SAIN, B. AND GRIFMAN, P. 1982. Management of marine conflicts: the role of third parties. Conference on Marine Resource Management and the Future Role of the State of California, Asilomar, California, November 1982.
GRIFMAN, P. In prep. Conflicts between offshore oil development and commercial fisheries in California. (Working title).

VITAMIN AND MINERAL METHODS DEVELOPMENT AND STANDARDIZATION FOR ASSESSING THE NUTRITIONAL VALUE OF COOKED FISH

San Diego State University
R/NP-1-11J
1981-82

Ronald V. Josephson and Audrey A. Spindler

The basic gross composition information of many common fish in the raw state has been reported, but information on vitamin and mineral content is limited. Furthermore, data on nutrient losses (versus retention) caused by commercial or home cooking practices, and as affected by commercial storage, are severely lacking. At present, the paucity of data on this subject limits public access to important dietary information and potential proportional benefits to be gained from availability of this information.

Therefore, a pilot study was initiated through partial funding from the National Fisheries Institute, the trade association for the fisheries industry, to determine the effects of cooking on the nutritional value of chill-stored marine fish, beginning with the Bocaccio rockfish, *Sebastes paucispinus*. Available year-round and marketed as Pacific red snapper, this fish species has a moderate to high protein (19%) and low lipid (1%) content and is highly utilized commercially, but is of low to moderate market value. While nutritional information gained will have direct application and usage for other species of rockfish utilized locally and throughout the country, a study of larger scale is needed for fish of different compositions.

In order to obtain these data, modern analytical methodologies for vitamin and mineral quantification need to be adapted and standardized for fish. Sea Grant has provided rapid response funding (June 1982) for methodological development and standardization to set the groundwork for the fish nutrition study. The methods investigated included high performance liquid chromatography (HPLC) for vitamin assessment, and atomic absorption (AA) spectrophotometry for evaluation of mineral content of fish.

Vitamin Quantification by High Performance Liquid Chromatography (HPLC)

High performance liquid chromatography (HPLC or simply LC) is an analytical tool for quantification of vitamins that was adapted to the analysis of fish. At present with standard AOAC methods of analysis, each vitamin must be analyzed individually by widely different chemical, physical, and microbiological methods that are time consuming and often difficult to quantify due to interferences with other components in foods. HPLC offers the potential for rapid, selective separation and estimation of a variety of vitamins instead of the problematical, individual determinations. In fact, the difficulty with the currently used individual vitamin methods has been a prime factor in discouraging research on vitamin contents of fish and other food products.

The major focus in the rapid response study has been to adapt HPLC to the resolution and quantification of water soluble vitamins (thiamin, riboflavin, niacin, and B_6) known to be present in fish. The investigation has included determining optimal conditions for separation, resolution, and quantification of these vitamins. Separation and resolution were accomplished by using reverse phase columns and manipulating the type of mobile phase solvent system (i.e., concentration of aqueous versus organic solvents), the concentration of ion pairing reagent, and column length and solvent flow rate. Published reports indicate that reverse phase HPLC has been successfully used for quantifying vitamins in pharmaceutical formulations and some enriched food products.

Optimal separation and resolution of vitamins were achieved under the following conditions: reverse phase column: ultrasphere ODS (C18), 5-micron particle size, 15 cm x 46 mm O.D.; flow rate: 2 ml/min; mobile phase: 90% water, 10% acetonitrile, 0.0025 M hexanesulfonic acid (pH 2.8) in the water phase. Controlled solvent conditions and flow rate were achieved by using Altex Model 110A solvent metering pumps.

Quantification of vitamins separated by HPLC required ultraviolet (Hitachi Model 100-10 Spectrophotometer) and fluorescence (Laboratory Data Control Fluoro Monitor III Model 1311) detectors and an integrating recorder (Hewlett-Packard Model 3390). Niacin in fish muscle is in quantifiable amounts by ultraviolet spectrophotometry, but riboflavin and thiamine must be quantified by fluorometry. Work is still in progress on separation for quantification of thiochrome, the fluorescent derivative of thiamine.

Another major objective of this investigation was to determine appropriate procedures for optimal extraction and recovery of vitamins from fish muscle. Different aqueous acids (hydrochloric acid or sulfuric acid) digesting with and without enzymes and autoclaving have been evaluated. Interfering compounds have been removed by using protein precipitation agents, centrifugation, and membrane filtration. Results indicate some residual ultraviolet absorbing chromatographic peaks near niacin (nicotinic acid and niacinamide) peaks. Chromotographic conditions are being modified to improve resolution of niacin peaks.

It is anticipated that refinement and standardization of HPLC methodologies and fish digestion procedures will be completed by the end of 1982 in time for their use in the study of the nutritional assessment of cooked fish.

Mineral Quantification by Atomic Absorption Spectrophotometer

Currently, methodology standardization for quantification of mineral content in fish has been focused on establishing two things: 1) if possible, a single digestion procedure appropriate for all minerals under consideration and 2) conditions for analyzing mineral contents using flame analysis. A National Bureau of Standards (NBS) reference standard sample, albacore tuna, has been used for methods development since its mineral content is somewhat similar to that of *Sebastes paucispinus*.

Few reports exist in the literature relevant to digestion with an acid digestion bomb. Conditions appropriate for complete digestion using the bomb have been established as 45 minutes at 150°C in concentrated nitric acid. Temperatures above 150°C are likely to cause explosions, but lower temperatures (100-125°C) have produced incomplete digestion, unless the time was extended extensively (2 hours). The bomb reduces loss from volatility and significantly shortens digestion time; however, since the maximum sample capacity is only 0.1 g (dry weight), use of the bomb for minerals found in very low concentration (ppb), such as Mn and Cu, may be precluded.

The approximate concentration of minerals found in ppm in fish (Zn, Fe, Ca, Mg, Na, and K) can be estimated on the acid digest, but to eliminate matrix interferences, digested samples are chelated with sodium diethyldithiocarbamate (NDDC) and extracted with methyl isobutyl ketone (MIBK). Conditions for and recoveries with standards of zinc are within the ranges established by the albacore reference. Presently these same approaches are being used for the other minerals found in ppm. It is expected that another digestion procedure, employing a larger sample size and flameless techniques (graphite furnace), will have to be developed for quantifying minerals at ppb. Progress is envisioned so that these procedures will be finalized for the cooked fish study in January 1982.

Cooperating Organizations
J. J. Camillo Seafood Brokerage Company
Chesapeake Fish Company, Inc.
Ghio Seafood Company
National Fisheries Institute

USE OF UNDERWATER HABITAT AS CORAL REEF RESEARCH TOOLS

University of California, Davis
A/C-P-1
1980-81

Steve Neudecker

The purpose of this project was to organize and conduct a special session of the Fourth International Coral Reef Symposium at Manila, Philippines, May 1981.

At the invitation of Dr. Edgardo Gomez, chairman of the symposium organizing committee, on November 19, 1980, I began to prepare a special session on the use of underwater habitats as coral reef research tools. Internationally known scientists who had habitat experience were contacted for their ideas and asked to join the session as panel members.

On April 5, 1981, I traveled to Hawaii to meet with directors of the Hawaiian Undersea Research Laboratory (HURL) regarding the special session. I also stopped in Guam en route to Manila to confer with panel member Dr. Charles Birkeland. I arrived in Manila May 17 and began final preparations for the meeting.

About 150 persons attended the session, asked questions, and received written materials. The meeting went very well and much valuable information was exchanged.

Cooperating Organizations
National Oceanic and Atmospheric Administration
University of California, Davis

Publications

NEUDECKER, S. 1981. Effects of substratum orientation, depth, and time on coral recruitment at Guam. Paper presented at Fourth International Coral Reef Symposium, Manila, Phillipines, May 1981.

NEUDECKER, S. 1981. Growth and survival of scleractinian corals exposed to thermal effluents at Guam. Paper presented at Fourth International Coral Reef Symposium, Manila, Phillipines, May 1981.

NEUDECKER, S. AND LOBEL, P. S. In press. 1981. Mating systems of chaetodontid and pomacanthid fishes at St. Croix. Paper presented at Fourth International Coral Reef Symposium, Manila, Phillipines, May 1981. Also in Z. *Tierpsychol.*

APPENDIX

SEA GRANT PROJECTS LIST
1980-1982

Management	**FY80**	**FY81**	**FY82**
Program Management (M/A-1, Sullivan)	O	O	O
Program Planning and Development (M/P-1, Sullivan)	O	O	O

Marine Education	**FY80**	**FY81**	**FY82**
Sea Grant Trainees (E/G-2, Sullivan)	O	O	O
Ocean Engineering and the Future: Long-Range Planning: A Graduate Seminar (E/G-8, Webster/Tulin)	N/C	—	—
A History of the Santa Barbara Channel (E/UG-2, Talbott)	N	O	O
John D. Isaacs Memorial Scholarship (E/UG-4, Sullivan)	—	N	O
Reorganizing and Updating an Advanced Course in Marine Policy (R/NP-1-11E, Revelle)	—	—	N/C

Marine Advisory	**FY80**	**FY81**	**FY82**
Marine Advisory Program (A/EA-1, Price)	O	O	O
Publications and Public Advisory Services (A/P-1, Frautschy)	R	—	—
Communications, Publications, and Public Advisory Services (A/P-1, Sullivan)	R	O	O
Ocean Education for the Public (A/PE-1, Wilkie et al.)	O	O	O
The Golden Gate Marine Center (R/NP-1-9D, Caya)	N/C	—	—
Mobile Marine Science Outreach Program (R/NP-1-9J, Bauer)	N	C	—

Coastal Resources	**FY80**	**FY81**	**FY82**
Wetlands Management in Coastal Zone Planning: A Prototype Framework for Relating Natural Science and Land-Use Planning (R/CZ-45, Dickert/Nybakken)	C	—	—
An Experimental Program to Develop Methods for Kelp Bed Expansion and Enhancement (R/CZ-46, Neushul/Coon)	C	—	—
A Study of the Entrance Problems at Humboldt Bay (R/CZ-47, Isaacs/Kerstetter)	C	—	—
Analysis of Coastal Ocean Mixing Models (R/CZ-48, List/Morgan)	N	C	—
Coastal Wetlands Management: Restoration and Establishment (R/CZ-51, Zedler)	N	O	O
Coastal Wetlands Management: Application of Biological Criteria (R/CZ-52, Onuf et al.)	N	O	C
Investigation of Coastal Bluff Retreat for the Trinidad Headland Area of Northern California (R/CZ-53, Carver)	N/C	—	—
Phosphorites Along the Central California Continental Margin (R/CZ-54, Mullins)	—	N	C
Salt Marsh Restoration: An Ecological Evaluation of an Estuarine Mitigation Project (R/CZ-56, Barnhart/Boyd)	—	N/C	—
Planning Methods for California's Coastal Wetland Watersheds (R/CZ-57, Dickert)	—	N	O
Sea Urchin Diseases (R/CZ-58, Hinegardner et al.)	—	N	C
Water Currents and Mixing Rates in Kelp Beds (R/CZ-59, Jackson/Winant)	—	N	O
Liquefaction Potential of Coastal Fills (R/CZ-61, Noorany)	—	N/C	—
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	—	—
Studies of Light and Life in Natural Waters (R/NP-1-10C, Tyler)	—	N/C	—
Coastal Zone Geology and Related Sea Cliff and Bluff Erosion: Oceanside South to Batiquitos Lagoon, Carlsbad, Oceanside Littoral Cell, San Diego County, California (R/NP-1-10E, Shepard)	—	N/C	—

	FY80	FY81	FY82
Investigation of Coastline Retreat, Humboldt County, Northern California (R/NP-1-10F, Rust)	—	N	C
Longard Tube Survey and Documentation, Del Mar, California (R/NP-1-10G, Flick)	—	N/C	—
Workshop on Coastal Wetland Restoration and Enhancement (R/NP-1-10H, Josselyn)	—	N	O
Use of Underwater Habitat as Coral Reef Research Tools (A/C-P-1, Neudecker)	—	N/C	—

Aquaculture	FY80	FY81	FY82
Development of the Science and Technology of Crustacean Aquaculture (R/A-28, Clark/Hand et al.)	O	C	—
Control of Reproduction in the Decapod Crustaceans (R/A-29, Talbot)	O	C	—
Studies to Refine Hatchery and Ocean Rearing Methods for the Purple-Hinge Rock Scallop (R/A-31, Phleger/Leighton)	C	—	—
Biochemical and Genetic Control of Critical Physiological Processes in Molluscan Life-Cycles: Basic Mechanisms, Water-Quality and Sensitivities to Pollutants (R/A-32, Morse)	C	—	—
Culture of Marine Bivalves: Effects of the Uptake of Amino Acids (R/A-33, Stephens)	O	C	—
Aquaculture of Red Algae (R/A-34, Abbott)	C	—	—
An Exploratory Study of the Vegetative Propagation of Benthic Marine Algae (R/A-37, Gibor/Neushul)	O	C	—
Protective Measures Against *Fusarium* Disease in Shrimp (R/A-38, Steenbergen/Lightner)	N	C	—
Assessment of Sperm-Egg Interactions During Fertilization and Hybrid Formation of California Abalones (R/A-39, Vacquier)	N	C	—
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	C	—
Food and Fiber from Seawater, Sand, and Solar Energy (R/A-42, Epstein)	N	C	—
Biochemical Engineering for Improved Production of Commercially Valuable Marine Shellfish (R/A-43, Morse)	—	N	O
Artificial Control of Gametogenesis, Spawning, and Larval Production in the Purple-Hinge Rock Scallop (R/A-44, Phleger/Leighton)	—	N	O
Aquatic Animal Production (R/A-45, Clark/Conklin)	—	—	N
Development of Procedures for Artificial Insemination and Sperm Storage in Lobsters (R/A-46, Talbot)	—	—	N
Variation in Intracellular pH and Its Effect on Hatchability of Cysts of the Brine Shrimp *Artemia salina* (R/A-47, Crowe)	—	—	N
Culture of Marine Bivalves; Nutritional Role of Dissolved Organic Solutes (R/A-48, Stephens)	—	—	N
Physiological Aspects of *Porphyra perforata* Mariculture: The Effect of Desiccation on Photosynthesis and on the Control of Epiphytes (R/A-49, Abbott)	—	—	N/C
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	—	—
Seasonal Growth Responses of Vegetative Axes and Spores of an Agar-Producing Marine Alga (R/NP-1-10B, Stewart)	—	N/C	—
Vegetative Propagation of Commercially Important Benthic Algae (R/NP-1-11A, Gibor)	—	—	N
The Effects of Environmental Factors on the Ability of Chemical Cues to Trigger Settlement and Metamorphoses of Bivalve Larvae (R/NP-1-11F, Shaw)	—	—	N
Control of Egg Drop in the Lobster, *Homarus americanus* (R/NP-1-11G, Talbot/Hedgecock)	—	—	N/C

Fisheries	FY80	FY81	FY82
Improved Marine Food Products and Marine Food Technology (R/F-32, Brown)	C	—	—
Design and Development of a Squid Processing Machine (R/NP-1J, R/F-33, Singh)	C	—	—
Bioconversion of Chitin Wastes (R/F-34, Carroad)	C	—	—
Development of Multispecies Management for Kelp Bed Resources with an Emphasis on Sea Urchins (R/F-36, Tegner)	O	C	—

	FY80	FY81	FY82
The Effects of Food Availability on the Growth and Survival of California Jack Mackerel Larvae (R/F-44, Mullin/Lasker)	C	—	—
Endocrinology of Normal and Abnormal Salmon Smoltification and Adaptation to Seawater (R/F-45, Bern)	O	C	—
Artificial Imprinting of Chinook Salmon in a Multispecies Hatchery (R/F-46, Hassler)	C	—	—
Experimental Abalone Enhancement Program (R/F-47A, Tegner)	O	C	—
Experimental Abalone Enhancement Program (R/F-47B, Connell)	C	—	—
Sensory and Behavioral Effects of Pollutants on the Crab and Lobster Fishery (R/F-48, Case)	C	—	—
Genetic Improvement of a Chitinase-Producing Microorganism (R/F-50, Ogrydziak)	C	—	—
Coordination of Federal, Regional, and State Policies for Managing Marine Fisheries (R/F-51, Moore/Wyner/Cicin-Sain)	C	—	—
Economics of Fisheries and Aquaculture Development (R/F-52, Johnston/Hand)	O	O	C
An Economic Analysis of the California Abalone Fishery and the Experimental Enhancement Program (R/F-53, Deacon)	O	C	—
Assessment of Aging Techniques and Their Application to Elasmobranch Fisheries (R/F-57, Cailliet)	N	C	—
Multiple Species Utilization of the Herring Eggs-on-Seaweed Fishery (R/F-58, Abbott)	N	C	—
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	C	—
Economics of Multipurpose Fishing Vessels: Assessment and Policy (R/F-61, Holt)	N	C	—
A New Method for Estimating the Energy Available to Fisheries (R/F-62, Mullin/Goodman)	—	N	C
Functional Structure of Fish Assemblages of the Southern California Sublittoral Soft-Bottom Habitat (R/F-63, Rosenblatt)	—	N/C	—
Anchovy Management and Stock Assessment: Seabird Reproduction as an Indicator (R/F-64, Hunt)	—	N	C
Parasites as Biological Tags for Pacific Herring Stock Identification (R/F-65, Moser)	—	N/C	—
Improving Efficiency of Commercial Shell- fishing by Analysis of Bait and Trap Functions (R/F-67, Case)	—	N	O
Seafood Science and Technology: Modified Atmosphere Storage (R/F-68, Brown)	—	N	C
Seafood Science and Technology: Microbiology of Fish (R/F-69, Barrett/Ogrydziak)	—	N	C
Chitin Waste Utilization (R/F-70, Carroad/Ogrydziak)	—	N/C	—
Water Conservation and Pollution Abatement in Seafood Processing Through Water Recycling (R/F-71, Carroad/Price)	—	N	C
Vital Statistics of the Female Stock of Dungeness Crab (*Cancer magister*) in Northern California (R/F-72, Hankin)	—	N	O
Evaluation of the Experimental Abalone Enhancement Program (R/F-73, Tegner)	—	—	N
Field Evaluation of An Abalone Enhancement Test Plant (R/F-74, Schmitt)	—	—	N/C
Effect of Nemertean Egg Predators on the Dungeness Crab Fishery (R/F-75, Kuris)	—	—	N
Genetic Structure of Coho Salmon Populations on the Pacific Coast (R/F-76, Gall/Utter)	—	—	N
Artificial Imprinting of Chinook and Coho Salmon in a Multispecies Hatchery (R/F-77, Hassler)	—	—	N
Endocrine Control of Salmonid Development and Seawater Adaptation (R/F-78, Bern/Nicoll)	—	—	N
Biochemistry of Fat Depletion During Salmonid Smolt Transformation (R/F-79, Kerstetter/Allen)	—	—	N/C
An Economic Analysis of the Gains from Joint Management of Fishery Stocks (R/NP-1-9A, Johnston/Howitt)	N/C	—	—
Feasibility of Mechanical Skinning of Blue Shark (R/NP-1-9B, Singh/Katz)	N/C	—	—

	FY80	FY81	FY82
An Isotopic Aragonite-Water Temperature Scale Determined From Selected Shell-Bearing Marine Organisms (R/NP-1-10D, Shull)	—	N/C	—
Aquarium Energetics and Growth Rates of *Anoplopoma fimbria* (R/NP-1-10I, Somero)	—	—	N/C
Age and Growth of Pelagic Sharks: Management Information for California's Emerging Fisheries (R/NP-1-11C, Cailliet)	—	—	N/C
Vitamin and Mineral Methods Development and Standardization for Assessing the Nutritional Value of Cooked Fish (R/NP-1-11J, Josephson/Spindler)	—	—	N

New Marine Products	**FY80**	**FY81**	**FY82**
Marine Plants as a Source of Insect Growth Inhibitors (R/MP-14, Crews)	C	—	—
Pharmacological Evaluation Program (R/MP-15, Jacobs)	C	—	—
Marine Natural Products for Pharmacological Evaluation (R/MP-16, Faulkner)	C	—	—
New Agricultural Chemicals from Marine Organisms (R/MP-18, Fenical)	C	—	—
Antiviral Compounds from Algae (R/MP-20, Vedros)	C	—	—
Marine Chemistry and Pharmacology Program: Pharmacological Screening and Evaluation (R/MP-21, Jacobs)	—	N	O
Marine Chemistry and Pharmacology Program: Chemical Studies of Tropical Marine Algae and Coelenterates (R/MP-22, Fenical)	—	N	O
Marine Chemistry and Pharmacology Program: Chemistry of Sponges and Opisthobranch Molluscs (R/MP-23, Faulkner)	—	N	O
Marine Chemistry and Pharmacology Program: Natural Products from Toxic Marine Organisms (R/MP-24, Crews)	—	N	O

Ocean Technology	**FY80**	**FY81**	**FY82**
Earthquake Loading on Large Offshore Structures: An Application of Experimental Data to Practical Structure Forms (R/E-14, Penzien)	C	—	—
Side-Scan Sonar Mapping and Computer-Aided Interpretation of the Geology of the Santa Barbara Channel (R/E-18, Luyendyk/Simonett)	C	—	—
A Condensing Turbine for the Distillation of Seawater (R/E-22, Manalis/Lee)	C	—	—
Temperature Tolerances of Benthic Marine Invertebrates and Their Relationship to Regulatory Requirements for Thermal Effluent (R/E-23, Ford/Van Olst)	C	—	—
Earthquake-Induced Forces on Nonaxisymmetric Offshore Structures (R/OT-1, Wiegel)	—	N	O
Hydrodynamics of Harbor Entrances and the Maneuverability of Ships Moving Through Entrances (R/OT-2, Webster)	—	N	O
TV/Sonar Imaging System (R/OT-3, Anderson)	—	N	O
Development of a Methodology for the Design, Construction, and Quality Assurance of the Core of Rubble-Mound Breakwaters (R/OT-5, Gerwick)	—	—	N
Design of a Sea-Floor Work System (R/OT-6, Anderson)	—	—	N
Bioelectric Toxicity Assaying (Phase I) (R/NP-1-9M, Anderson)	N	O	C
Application of Advanced Methods of Magnetic Reconnaissance (R/NP-1-10A, Macdonald/Miller)	—	N	C

Marine Affairs	**FY80**	**FY81**	**FY82**
Statistical Forecasting Methods for Fisheries Management (R/MA-1, Wilen/Howitt)	—	N	C
Management of Multispecies Systems: The Pacific Hake Example (R/MA-2, Goodman)	—	N	O
Improved Procedures for Salmon Management in California: Bioeconomic Approaches (R/MA-3, Wilen/Botsford)	—	N/C	—
Analysis of Industrial Organization of Commercial Pacific Marine Fishery Markets (R/MA-4, Garoyan)	—	N	O
A Study of Direct and Indirect Economic Linkages Associated with the California Seafood Industry and an Analysis of Their Impacts on the Employment, Income, and Level of Economic Activity in California (R/MA-5, King)	—	N	C
Technological Change in the Salmon Canning Industry: Blaine, Washington, 1890-1930 (R/MA-6, Scheiber)	—	N/C	—

	FY80	FY81	FY82
A History of the Commercial Fishermen of Monterey Bay—The Role of Public Policy (R/MA-7, Brownlee)	—	N	C
The Role of Individual Perception and Structural Position in the Development of Fishery Management Policy (R/MA-8, Orbach)	—	N	C
Marine Mammals/Fisheries Conflicts: Emphasis on Sea Otter/Shellfish Fisheries Conflicts in California (R/MA-9, Cicin-Sain)	—	N/C	—
Coastal Transit Service Options and Policy (R/MA-10, Banks/Stutz)	—	N	O
Law, Ecology, and Economic Change: The California Fisheries, 1850-1980 (R/MA-13, Scheiber)	—	—	N
The Politics and Policy Implications of Deep Seabed Mining: U.S. Options (R/NP-1-8I Mann)	N	C	—
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	C	—
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	—	—
Economic Analysis of the Impact of Aquaculture on Commercial Fisheries (R/NP-1-11B, Johnston/Wilen)	—	—	N
The Distribution and Interpretation of the 1980 CIF Model and the Refinement of User-Oriented Computer Programs (R/NP-1-11D, King)	—	—	N
Exploring Conflicts Between Offshore Oil Development and Commercial Fishing in California (R/NP-1-11H, Mann)	—	—	N/C
Rapid Response			
Rapid Response Capability (R/NP-1, Sullivan)	O	O	O

C = Completed; N = New; O = Ongoing; R = Restructured

Activity Budget

1980-1981

	NOAA Grant Funds	Matching Funds
Marine Resources Development		
Aquaculture	$ 437,842	$ 521,256
Living Resources	236,626	169,030
Mineral Resources	10,022	23,900
Marine Biomedicinals & Extracts	171,478	112,333
Socioeconomic and Legal Studies		
Marine Economics	130,205	96,482
Marine Recreation	31,059	21,869
Sociopolitical Studies	25,560	22,025
Marine Technology Research and Development		
Ocean Engineering	66,802	60,034
Resources Recovery and Utilization	70,269	95,594
Transportation Systems	50,756	36,448
Marine Environmental Research		
Research and Studies in Direct Support of Coastal Management Decisions	20,737	25,426
Ecosystems Research	77,095	51,596
Environmental Models	79,403	31,959
Marine Education and Training		
Other Education	477,360	49,140
Advisory Services		
Extension Programs	587,684	253,916
Other Advisory Services	188,255	114,903
Program Management and Development		
Program Administration	266,907	229,350
Program Development	221,940	45,267
TOTAL	$3,150,000	$1,960,528

Activity Budget
1981-1982

	NOAA Grant Funds	Matching Funds
Marine Resources Development		
Aquaculture	$ 387,105	$ 385,228
Living Resources, Other Than Aquaculture	266,216	194,508
Marine Biomedicinals & Extracts	177,661	113,688
Socioeconomic and Legal Studies		
Ocean Law	22,294	25,931
Marine Recreation	30,505	26,680
Sociopolitical Studies	12,771	10,413
Marine Technology Research and Development		
Ocean Engineering	139,348	174,900
Resources Recovery and Utilization	89,784	87,474
Transportation Systems	57,757	16,084
Marine Environmental Research		
Research and Studies in Direct Support of Coastal Management	32,037	26,233
Ecosystems Research	89,736	52,125
Environmental Models	89,743	31,795
Marine Education and Training		
Other Education	481,174	18,069
Advisory Services		
Extension Programs	555,809	160,912
Other Advisory Services	198,244	87,759
Program Management and Development		
Program Administration	270,657	194,439
Program Development	249,159	27,494
TOTAL	$3,150,000	$1,633,732

MATCHING FUNDS SOURCES

Matching Funds Sources 1980-1981

State of California:	
California Resources Agency	$ 392,500
Department of Fish and Game	31,733
Aquarium-Museum Docents	30,262
Bristol-Myers	7,860
California Seafood Institute	21,150
Counties of: Monterey, San Diego, San Francisco, San Luis Obispo, San Mateo, Santa Barbara, and Sonoma	50,640
Donations	38,948
Hydro Products Inc.	6,460
Johnson Oyster	2,010
Marine Colloids	12,640
Meredith Fish Company	2,620
P&R Systems	2,000
Syntex Corporation	45,195
TransFresh Corporation	5,930
Zoecon	1,500
California Institute of Technology	8,900
Humboldt State University	23,677
Humboldt State University Foundation	753
San Diego State University	90,189
San Diego State University Foundation	3,260
San Jose State University/Moss Landing Marine Laboratories	32,966
Stanford University	16,350
University of Arizona	4,950
University of California	1,125,064
University of North Carolina	2,971
TOTAL	$1,960,528

Matching Funds Sources 1981-1982

State of California:	
California Resources Agency	$ 196,250
Department of Fish and Game	99,146
State of Washington:	
Department of Fish and Game	2,400
Bristol-Meyers	8,000
Canadian Fisheries Research Board	2,400
Donations	9,497
Hydro Products	12,160
Johnson Oyster Company	1,500
Meredith Fish Company	3,000
Program and Remote Systems	10,000
Santa Barbara County Parks	7,247
Syntex Corporation	34,500
Humboldt State University	18,383
San Diego State University	74,985
San Jose State University	5,222
Stanford University	23,476
University of California	1,123,166
University of Oregon	2,400
TOTAL	$1,633,732

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA

Regents Ex Officio

Edmund G. Brown, Jr.
Governor of California and President of the Regents

Mike Curb
Lieutenant Governor of California

Willie L. Brown, Jr.
Speaker of the Assembly

Wilson Riles
State Superintendent of Public Instruction

Lois W. Weeth
President of the Alumni Association of the University of California

Stanley A. Walner
Vice-president of the Alumni Association of the University of California

David S. Saxon
President of the University

Appointed Regents

Edward W. Carter
DeWitt A. Higgs
Glenn Campbell
William French Smith
Robert O. Reynolds
Dean A. Watkins
Joseph A. Moore
John H. Lawrence, M.D.
William A. Wilson
Vilma S. Martinez
John F. Henning
Stanley K. Scheinbaum
Yori Wada
Willie L. Brown, Jr.
Frank W. Clark, Jr.
David Geffen
Willis W. Harman
David A. Neuman

Regents-designate

Shirley Brown Conner
Frank S. Phillips

Faculty Representatives

Oliver A. Johnson
Robert E. Connick

OFFICERS OF THE SYSTEMWIDE ADMINISTRATION

David S. Saxon
President of the University

David A. Wilson
Executive Assistant to the President

William B. Fretter
Vice-president of the University

William R. Frazer
Academic Vice-president

Archie Kleingartner
Vice-president—Academic and Staff Personnel Relations

James B. Kendrick, Jr.
Vice-president—Agriculture and University Services

Dorothy E. Everett
Assistant President—Coordination and Review

Baldwin G. Lamson
Vice-president—Financial and Business Management

Lowell J. Paige
Special Assistant to the President for Governmental Relations

Officers Emeriti

Charles J. Hitch
President of the University, Emeritus; Professor of Economics, Emeritus

Clark Kerr
President of the University, Emeritus; Professor of Business Administration, Emeritus

Vernon I. Cheadle
Chancellor, Emeritus; Professor of Botany, Emeritus

Ivan H. Hinderaker
Chancellor, Emeritus; Professor of Political Science, Emeritus

Dean E. McHenry
Chancellor, Emeritus; Professor of Comparative Government, Emeritus

Emil Mrak
Chancellor, Emeritus; Professor of Food Science and Technology, Emeritus; Food Technologist in Experiment Station, Emeritus

John B. de C. M. Saunders, M.D.
Chancellor, Emeritus; University Librarian, Emeritus; Professor of Anatomy, Emeritus; Professor of History of Health Sciences, Emeritus

Albert H. Bowker
Chancellor, Emeritus; Professor of Statistics, Emeritus

Angus E. Taylor
Chancellor, Emeritus; University Provost, Emeritus; Professor of Mathematics, Emeritus

Harry R. Wellman
Vice-president of the University, Emeritus; Professor of Agricultural Economics, Emeritus; Agricultural Economist, Emeritus

Thomas E. Jenkins
Vice-president—Budget Plans and Relations, Emeritus

John A. Perkins
Vice-president—Business and Finance, Emeritus; Professor of Political Science, Emeritus

Clinton C. Powell, M.D.
Special Assistant to the President—Health Affairs, Emeritus

Chancellors

Ira Michael Heyman
Chancellor at Berkeley

James H. Meyer
Chancellor at Davis

Daniel G. Aldrich, Jr.
Chancellor at Irvine

Charles E. Young
Chancellor at Los Angeles

Tomás Rivera
Chancellor at Riverside

Richard C. Atkinson
Chancellor at San Diego

Francis A. Sooy
Chancellor at San Francisco

Robert A. Huttenback
Chancellor at Santa Barbara

RESOURCES AGENCY SEA GRANT ADVISORY PANEL

E. C. Fullerton, Chairman
Director
Department of Fish and Game
12th Floor, Resources Building
Sacramento, California 95814

Michael L. Fischer
Executive Director
California Coastal Commission
631 Howard Street
San Francisco, California 94105

Jeffery D. Frautschy
Retired, Associate Director
Scripps Institution of Oceanography
2625 Ellentown Road
La Jolla, California 92037

Tom Gay
Chief Deputy State Geologist
Division of Mines and Geology
1416 9th Street, Room 1341
Sacramento, California 95814

Stephen P. Henderson**
Aquaculture Marketing Services, Ltd.
P.O. Box 1872
Monterey, California 93940

Marty Mercado
Director
Department of Boating and Waterways
1629 "S" Street
Sacramento, California 95814

Richard Ridenhour
Dean, College of Natural Resources
Humboldt State University
Arcata, California 95521

Rob Ross
Associate Director of Legislative Relations
California Seafood Institute
11th and "L" Building, Suite 1003
Sacramento, California 95814

Hugh W. Staton
Estero Bay Mariculture
P.O. Box 136
Cayucos, California 93430

Wilbur M. Thompson, Manager
Long Beach Operations
State Lands Commission
100 Oceangate Street, Room 300
Long Beach, California 90802

Donald Walsh
Director
USC Institute for Marine and Coastal Studies
University of Southern California
University Park
Los Angeles, California 90007

Elmer P. Wheaton
Retired, Vice-president, Lockheed
127 Solana Road
Portola Valley, California 94025

* Members serving in 1980-1982
** Term ended September 1981

IMR ADVISORY COUNCIL **1980-1982**

William A. Nierenberg, Chairman
Director
Scripps Institution of Oceanography
Vice-chancellor—Marine Sciences
University of California, San Diego
A-010
La Jolla, California 92093

Izadore Barrett
Director
Southwest Fisheries Center
National Marine Fisheries Service
P.O. Box 271
La Jolla, California 92038

Willard Bascom
Director
Southern California Coastal
Water Research Project
646 West Pacific Coast Highway
Long Beach, California 90806

Hugo Fisher
San Diego Superior Court
Department 29
220 West Broadway
San Diego, California 92101

Tod Ghio
Ghio Seafood Products
5232 Lovelock
San Diego, California 92110

W. F. Grader, Jr.
General Manager
Pacific Coast Federation
of Fishermen's Associations
3000 Bridgeway Bldg., Suite 104
P.O. Box 1626
Sausalito, California 94966

F. J. Hortig*
Consulting Engineer
2216 Westboro
Alhambra, California 91803

Robert A. Huttenback
Chancellor
University of California, Santa
Barbara
5221 Cheadle Hall
University of California
Santa Barbara, California 93106

Herbert R. Kameon
Chairman of the Board
National Coalition for Marine
Conservation, Pacific Region
365 - 25th Street
Santa Monica, California 90402

Gerald G. Loehr
Group Vice-president
AMETEK
790 Greenfield Drive
El Cajon, California 92022

Max Loewe
Technical Director
Star-Kist Foods, Inc.
Terminal Island, California 90731

Hayden A. Moore*
3749 Rosecroft Lane
San Diego, California 92106

Russell R. O'Neill
Dean, School of Engineering and
Applied Sciences
7400 Boelter Hall
University of California
Los Angeles, California 90024

John J. Royal*
Secretary-treasurer
Fisherman's Union ILWU Local 33
806 South Palos Verdes Street
San Pedro, California 90731

M. Lea Rudee
Provost, Warren College
Professor of Electrical Engineering
University of California, San Diego
Q-022
La Jolla, California 92093

Nathan Sonenshein
RADM, USN (Retired)
Assistant to the President
Global Marine Development, Inc.
P.O. Box 3010
Newport Beach, California 92663

Ellen Weaver
Professor of Biological Sciences
School of Science
San Jose State University
San Jose, California 95192

Elmer P. Wheaton
Vice-president, Lockheed, Retired
127 Solana Road
Portola Valley, California 94025

Nicholas Yaru
Vice-president and Assistant
Group Executive
Hughes Aircraft
P.O. Box 3310
Fullerton, California 92634

* Term ended August 1981

IMR EXECUTIVE COMMITTEE

IMR

F. N. Spiess, Chairman
Director
Institute of Marine Resources
A-028
University of California
La Jolla, California 92093

Berkeley

J. R. Paulling
Naval Architecture & Offshore
Engineering, 202-A NAB
University of California
Berkeley, California 94720

Davis

Wallis H. Clark
Director
Aquaculture Program
254 Animal Science
University of California
Davis, California 95616

Irvine

Grover C. Stephens
Dean
School of Biological Sciences
331 Steinhaus Hall
University of California
Irvine, California 92717

Los Angeles

R. R. O'Neill
Dean
School of Engineering & Applied
Science
7400 Boelter Hall
University of California
Los Angeles, California 90024

Riverside

James J. Sims
Plant Pathology
3401 Webber Hall East
University of California
Riverside, California 92521

San Diego

William A. Nierenberg
Director
Scripps Institution of Oceanography
A-010
University of California, San Diego
La Jolla, California 92093

Santa Barbara

Henry W. Offen
Director
Marine Science Institute
University of California
Santa Barbara, California 93106

Santa Cruz

William T. Doyle
Dean
Division of Natural Sciences
391 Applied Sciences Building
University of California
Santa Cruz, California 95064

Sea Grant College

James J. Sullivan
Program Manager
California Sea Grant College Program
Institute of Marine Resources
A-032
University of California
La Jolla, California 92093

---

*Members serving in 1983.

CALIFORNIA SEA GRANT COMMITTEE **1980-1982**

SEA GRANT PUBLICATIONS POLICY AND REVIEW COMMITTEE **1980-1982**

Isabella Abbott
Hopkins Marine Station
Stanford University
Pacific Grove, California 93950

Kelly Anderson
Communications Coordinator
Sea Grant College Program
A-032
University of California
La Jolla, California 92093

W. Duane Brown
Institute of Marine Resources
Department of Food Science
and Technology
University of California
Davis, California 95616

Wallis Clark
Director, Aquaculture
245 Animal Science
University of California
Davis, California 95616

Maynard Cummings[1]
Extension Wildlife and Sea Grant
554 Hutchison Hall
University of California
Davis, California 95616

William Fenical
Institute of Marine Resources
A-027
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California 92093

Suzanne Holt[2]
102 Crown College
University of California
Santa Cruz, California 95064

Dale Ingmanson
Department of Natural Sciences
San Diego State University
San Diego, California 92182

Warren Johnston
Department of Agricultural Economics
University of California
Davis, California 95616

Robert Price
Marine Advisory Program
101A Cruess Hall
Food Science & Technology
University of California, Davis
Davis, California 95616

Mia Tegner
Ocean Research Division
A-001
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California 92093

William Webster
201 Naval Architecture
University of California
Berkeley, California 94720

Joy Zedler
Department of Biology
San Diego State University
San Diego, California 92182

[1] Term ended June 1981

[2] Term ended September 1981

SEA GRANT AQUACULTURE INDUSTRY ADVISORY **1980-1982** COMMITTEE

Stephen Henderson, Chairman*
California Sea Farms
P.O. Box 1872
Monterey, California 93940

George Lockwood
Monterey Abalone Farms
300 Cannery Row
Monterey, California 93940

Richard Mack*
c/o Gerrapata Fisheries
P.O. Box 3178
Carmel, California 93921

James McBeth
Shellfish Unlimited
3739 Cascade Ct.
San Diego, California 92122

John McMullen
Ab Lab
Civil Engineering Lab
Port Hueneme, California 93043

Nate Shafer
Ocean Farmers, Inc.
P.O. Box 22173
Carmel, California 93922

Hugh W. Staton
Estero Bay Mariculture
P.O. Box 136
Cayucos, California 93430

Anthony Weaver
Pigeon Point Aquaculture Center
921 Pigeon Point Road
Pescadero, California 94060

* Term ended September 1981

SEA GRANT SEAFOOD INDUSTRY ADVISORY COMMITTEE 1980-1982

Tod Ghio, Chairman
Ghio Seafood Products
5232 Lovelock
San Diego, California 92110

Les Amundsen
Pt. St. George Fisheries
P.O. Box 1386
Santa Rosa, California 95403

Maurice Camillo
J. J. Camillo Seafood Brokerage
545 Harbor Lane
San Diego, California 92101

Robert Dean
International Pacific Seafood
11264 Rush Street
South El Monte, California 91733

Tom Elliott
Washington Fish and Oyster Company
185 Berry Avenue
P.O. Box 3894 Rincon Annex
San Francisco, California 94120

Mike LeMoi
K & C Food Sales
656 South Alameda Street
Los Angeles, California 90021

Bill Merry
W. R. Merry Seafood Company
636 Stanford Avenue
Los Angeles, California 90021

Ernest W. Peterson
Van Camp Seafood Company
11555 Sorrento Valley Road
San Diego, California 92121

Ray Swanson
Tom Lazio Fish Company, Inc.
Foot of "C" Street
Eureka, California 95501

Jerry B. Thomas
Eureka Fisheries, Inc.
P.O. Box 217
Fields Landing, California 95537