SEA GRANT IN CALIFORNIA

Developing and Protecting
Our Marine Resources

A PUBLICATION OF THE CALIFORNIA SEA GRANT COLLEGE SYSTEM

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Published by the California Sea Grant College System, University of California, La Jolla, California, 1996. Additional single copies are available free of charge from California Sea Grant College System, University of California, 9500 Gilman Drive, La Jolla, CA 92093-0232. (619) 534-4444.

Sea Grant is a unique partnership of public and private sectors, combining research, education, and technology transfer for public service. It is a national network of universities meeting changing environmental and economic needs of people in our coastal, ocean, and Great Lakes regions.

This work is sponsored in part by the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, under grant number NA36RG053, Project number A/P-1, and by the California State Resources Agency. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA, or any of their subagencies. The U.S. government is authorized to reproduce and distribute for governmental purposes.

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On the cover: A school of jack mackerel swims among the kelp forests of Southern California. Photo courtesy, Dale Glantz. Cover design, Steve Cook, Stephen Birch Aquarium-Museum Publications.

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Developing and Protecting Our Marine Resources

California Sea Grant College System
University of California
La Jolla, California 92093-0232
Publication No. R-041

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Introduction

"Marine resources...constitute a far-reaching and largely untapped asset of immense potential significance to the United States."

National Sea Grant College and Program Act of 1996

The National Sea Grant College Program, which today plays such a unique and important role in advancing the national interest in marine resources, was established by Congress in 1966, exactly thirty years ago. Its mission is broad: to hasten the development, use, and conservation of the nation's marine and Great Lakes resources.

In the intervening years, Sea Grant programs have been established in each of the coastal and Great Lakes states. These programs form the heart of a network of some 300 participating colleges and universities that work to provide a powerful national capability in marine research, outreach, and education.

The California Sea Grant College System, administered by the University of California, is the largest program in the network. The universities that participate in California Sea Grant are among the most pre-eminent marine science institutions in the nation and include not only the University of California and the California State University systems, but also private institutions of higher learning. Research that California Sea Grant sponsors at these universities through its highly competitive review processes addresses fundamental scientific questions with relevance to important marine issues and opportunities.

Recently, the National Sea Grant College Program, in conjunction with the National Oceanic and Atmospheric Administration (NOAA), completed a series of strategic planning exercises designed to chart the program's direction into the 21st century. The result is the *Sea Grant Network Plan, 1995–2005*.*

*An Executive Summary of the *Sea Grant Network Plan, 1995–2005* is available from California Sea Grant.

Because the number of issues inviting Sea Grant attention so far exceeds available resources, the *Plan* identifies the following goals by which Sea Grant can have its greatest impact within the broad areas of economic leadership, coastal ecosystem health and public safety, and education and human resources.

- **To advance technology for commercial products and processes through focus on commercial biotechnology and environmental technology;**
- **To aid the seafood production industry through focus on commercial fisheries, sustainable aquaculture, and seafood technology;**
- **To assist coastal economic development through focus on coastal business development, coastal community development, and revitalizing marine infrastructure;**
- **To protect and enhance coastal ecosystem health through focus on coastal ecosystems, habitats, and sustainable development;**
- **To ensure public safety through focus on coastal hazards and safety at sea;**
- **To provide a technically trained workforce through focus on human resource development, to include scientists and engineers, marine resource managers, and technically trained workers.**

In the pages that follow, we highlight some of the activities underway at California Sea Grant in support of these goals. Articles detail, among other examples, research designed to use advanced science and technology to increase aquaculture production, recover metals from polluted sediments, detect harmful bacteria in coastal waters, and conserve genetic diversity in threatened species. They describe outreach efforts to help government agencies and others use GIS to coordinate water quality and resource management plans, improve the quality of seafood, and educate the public on nonindigenous species. And they introduce a few of the 40 or so graduate students that the program supports annually. These talented young people, Sea Grant trainees, will one day move into professional careers in academe, government, and industry, and have rightly been described as Sea Grant's most important contribution to technology transfer.

In short, this publication describes just some of the contributions being made by California Sea Grant to the network's ambitious national agenda of marine science in the service of society.

James J. Sullivan
Director
California Sea Grant College System

Recovering Metals from Polluted Marine Sediments

When marine sediments become contaminated with metal pollutants from industry, they may become a health risk to people as well as to marine plants and animals.

Such sediments are a constant source of metal in seawater—a problem that is aggravated if the sediments are disturbed either by storms or by dredging. Present solutions, such as capping contaminated sediments or moving dredged materials elsewhere, are expensive and create yet another set of environmental problems.

With support from California Sea Grant and the UC Toxic Substances Research and Teaching Program, Dr. Bradley Tebo of UCSD's Scripps Institution of Oceanography, and his Sea Grant trainees (Yoon Lee, Christopher Francis, and Karen Casciotti) have been working to develop new processes for removing and recovering such metals as cobalt, iron, copper, and chromium from nearshore sediments.

"Metal pollution is really tough to deal with," Tebo explains. "You can degrade organic pollutants like oil to harmless by-products, but you can't destroy metals. The only option is to remove them."

The technique he is exploring relies on the fact that many bacteria can separate dissolved metals from water as solid metal precipitates. And Tebo believes that genetic manipulation can enhance microbes' metal-removing capabilites.

He further hopes to exploit the magnetic properties of the metal precipitates to remove them from sediments, using a technology called high-gradient magnetic separation. Biomagnetic separation of toxic metals could reduce the costs of sediment disposal by 90 percent or more by reducing sediment volume and toxicity—in addition, valuable metals would be recovered for recycling.

Cooperating with Tebo in this project are Biopraxis, Inc. of San Diego and the Mare Island Naval Shipyard in Vallejo, California. In addition, the Port of San Diego has provided him with sediment samples from sites in San Diego Bay.

Many bacteria can separate dissolved metals from seawater.

In one of the most promising marine bacteria he has studied (*Bacillus* sp. strain SG-1), the spore stage, not the vegetative cells, precipitates metals. SG-1 spores are capable of binding and/or oxidizing a variety of different metals and thus may be useful where mixed metals occur. In addition, because spores are dormant, organisms do not have to be grown and maintained in order to have metal-removing activity. "We could potentially use nonliving spores to precipitate metal contaminants, remove the metals from the spores, and recycle the spores," Tebo says.

Not only can the precipitated metals be removed, they act as "scavengers" for other metals and radioactive elements, which bind to the material.

In the next decade, given growing interest in both the health of the environment and the production of new materials, Tebo predicts rapid advances in this new frontier of bioremediation.

Manganese oxide precipitates coat the spores of the marine bacterium *Bacillus* sp. strain SG-1.

Predicting the Movement of Oil Spills

Predicting how an oil slick will move and spread across the ocean's surface is vital for planning spill containment and cleanup. How long will it take for the spill to beach? What is the likelihood it will reach a sensitive wetland? These are questions disaster-response teams must be able to answer, even when darkness or bad weather limits aerial observations.

But computer models designed to predict such movement are useful only to the extent that they take into account all the factors that determine which coastal areas will be most affected— factors such as tides, sea breezes, and ocean depth. According to Dr. Rodney Sobey, professor of civil engineering at UC Berkeley, most models virtually ignore perhaps the most important mechanism responsible for carrying oil onshore—waves.

"Oil slicks are transported primarily by surface currents," Sobey says. "When winds are light or absent, tidal currents and oceanic currents flow parallel to the shoreline and cannot move a slick onto a beach," he explains." However, surface waves are directed toward beaches and wetlands, and so are very important factors when calculating potential economic or environmental damage."

With support from California Sea Grant, Sobey, with his graduate trainee, Christopher Barker, tackled the problem of incorporating the effects of waves into predictive models. First, Sobey computed the movement of surface waves under idealized conditions. He came up with 600 different combinations of wave height, wave period, and water depth, plus predictions of wave velocity.

The velocities, however, were only applicable to situations where swells were uniform in direction and frequency. Usually, conditions are more complex. So Sobey's next step was to develop a description of the complete sea state—that is, to superimpose influences from all possible wave frequencies and directions. Further work allowed him to predict how waves moving over the continental shelf would be influenced by changes in bottom contours.

In order to interpret his results, Sobey used computer graphics to create an animated sequence of images depicting wave-driven transport of oil slicks. In these images the concentration of oil (that is, the thickness of the oil layer on the surface) is represented by contour patterns that reflect the changing properties of local waves. The graphics were built around scenarios suggested by the *American Trader* spill off Huntington Beach in 1990, but they can be run for a variety of wave conditions and water depths.

By calculating the potential impact of surface waves, Sobey has greatly improved the reliability of models that simulate the movement of oil spills. This increased accuracy should lead to more rapid and prudent response to spills and aid investigations of their impact.

By calculating the potential impact of surface waves, Sobey has greatly improved the reliability of models that simulate the movement of oil spills.

Teamwork Reveals Course of Dangerous Toxin

P. australis

Domoic acid is a natural toxin produced by some algae of the genus *Pseudo-nitzschia*, which is found throughout the world. A potent neurotoxin, it can bind to receptor nerve cells and excite them until they are damaged or die.

Before 1991, the only known outbreak of domoic acid poisoning in North America had occurred in 1987 near Prince Edward Island, Canada, when four people died and many suffered nausea, dizziness, dementia, and memory loss after eating contaminated mussels.

Then, in September 1991, hundreds of sick and dying pelicans and cormorants littered the shores of northern Monterey Bay. After an intense search, a state wildlife veterinarian, working with local and Canadian scientists, identified the culprit as domoic acid, never before detected in California waters. He showed that domoic acid had accumulated in anchovies, common prey for seabirds.

The discovery led health officials to warn consumers against eating razor clams and mussels and to postpone the 1991 Dungeness crab season in California, Oregon, and Washington.

With support from California Sea Grant and the UC Toxic Substances Research and Training Program, scientists at UC Santa Cruz discovered that the species responsible (the diatom *Pseudo-nitzschia australis*) is a regular inhabitant of Monterey Bay. The team included Drs. David Garrison, Mary Silver, and Ron Tjeerdema and their Sea Grant trainees, Peter Walz and Graeme Haywood.

Once the scientists realized that Monterey Bay supported at least one potentially toxic species of diatom, they developed a highly advanced analytical method using high-pressure liquid chromatography for isolating, identifying, and quantifying levels of domoic acid in seawater, plankton, and animal tissues.

Between 1992 and 1995, team members found that *P. australis* bloomed each spring and fall, with each bloom lasting one to three weeks. They also discovered that cultures of the diatom are capable of producing significant amounts of domoic acid throughout their life cycle, something not previously suspected (though one bloom unaccountably produced no detectable level of toxin).

On the other hand, they found that although zooplankton called copepods readily accumulate domoic acid when they feed on toxic diatoms, they do not retain the residues for long. "Copepods are representative of important prey species, so this finding suggests that transference of the toxin through the planktonic food chain may be limited to the period during blooms of the toxic species," Silver notes.

Researchers also discovered that domoic acid blooms are not new in Monterey Bay. Studies of *P. australis* in archival samples dating back to 1977 showed that *Pseudo-nitzschia* species known to produce domoic acid had been present in the bay in at least 12 of the previous 17 years, and probably long before that.

Birds have become sick several other times in the history of Monterey Bay. Hitchcock capitalized on a 1961 attack of frenzied seabirds in his classic film *The Birds*. "We strongly suspect that it was a domoic acid bloom that caused the birds' bizarre behavior in '61," Garrison says.

California officials monitoring shellfish for domoic acid have not issued warnings since 1991; and with regular testing, the danger to commercial seafood is considered small, Garrison says. But he is concerned that pismo clams, anchovies, sea scallops, and rock crabs that end up in sport fishers' buckets might pose a risk.

Researchers still don't know what triggers the blooms, why algae produce the toxin, or how it spreads through the food web. "This is clearly an area that will continue to need attention," says Tjeerdema.

An Acoustic View of Life in the Sea

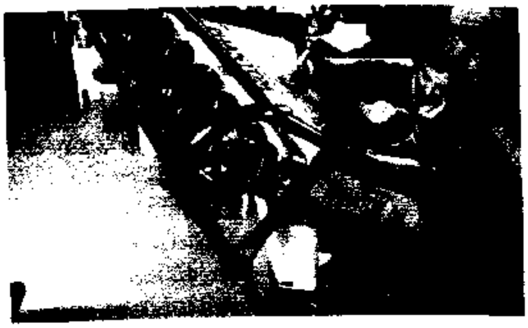
In the coming decade, underwater imaging systems based on sound will provide biologists with important new understandings about a wide range of marine animals.

With support from California Sea Grant and the National Science Foundation, Dr. Jules S. Jaffe, a research oceanographer at UC San Diego's Scripps Institution of Oceanography, and his Sea Grant trainee, Duncan McGehee, have been developing FTV (for "fish television"), a remote-sensing device that produces images from sound waves.

Jaffe initially created the sonar system to study zooplankton, tiny animals that form a critical link in the ocean's food web. FTV is the first remote-sensing device to precisely image the three-dimensional distribution of zooplankton, following them as they move in real time. Ultimately, it will allow biologists to answer such questions as, How do zooplankton react to each other and to predators? How dense are their schools?

The mechanics of producing images from sound waves works like this: A two-dimensional array of transmitters sends a single high-frequency (450 kHz) signal out into the water. Objects within the range of the pulse reflect the sound waves back to receivers. The time the pulse takes for its round trip, measured at a large number of angles, is then converted into a three-dimensional picture of the object's size and position. With acoustic readings taken many times per second, real-time movement can also be observed on a computer monitor. You don't actually see zooplankton or fish on the FTV monitor, but rather small blips of different colors.

In one overnight field test, FTV collected over 2,000 images in a volume of water about the size of a small room. After the data were processed, the movements of about 300 animal "targets" could be tracked. With the help of a video camera, Jaffe and McGehee identified these as crustacean zooplankton, as well as squid and small fish. They were able to estimate that the animals ranged from 10 mm to nearly 70 mm in length, based on the strengths of the acoustic signals.



Jaffe mounts the sonar sensor on the ROV *Phantom*.

FTV also recorded swimming patterns. Surprisingly, all of the animals in the images, whatever their size, swam at a broad range of speeds: sometimes darting, sometimes drifting. One interesting fact was that slowly moving animals followed paths with a tighter curve, behavior that would tend to lead to an aggregation of animals around a stimulus.

"There are any number of possible uses for this technology," says Jaffe, "from tracking migrating salmon, to measuring the density of farmed fish, to studying the dynamics of coral reefs." FTV can also be used by underwater robots to measure the distance of objects that are in the system's field of view.

While sonar sensors have a much greater range than video and camera systems, their disadvantage is inferior resolution—the details of the image aren't as clear. The best approach is to create a package that combines sonar and optical systems. Thanks to improvements in electronic hardware, Jaffe reports, the current version of FTV can generate images at higher frame rates, and the development of higher resolution images is just around the corner.

CALIFORNIA SEA GRANT

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Test for Virus Aids Sturgeon Aquaculture

A rapid and inexpensive new test for a virus that afflicts farmed white sturgeon has been developed by scientists at the UC Davis. With this tool, it may be possible to establish virus-free breeding populations of sturgeon and to avoid introducing new infections from fish caught in the wild.

Efforts to raise this important food fish in captivity were begun at the university nearly two decades ago, after it had become clear that the species was in severe decline as a result of overfishing, pollution, and dams that prevented their migration upstream.

Sturgeon are excellent candidates for fish farming. They are good to eat, grow well in confinement, and attain large size. However, early on a wasting disease appeared among the juvenile cultured fish. At first, the cause of this disease was a mystery, but eventually it was traced to what came to be called the White Sturgeon Iridovirus (WSIV).

"We know almost nothing about this particular virus," explains Dr. Ronald P. Hedrick, a member of the Department of Medicine/Epidemiology at the Davis Veterinary School. "In fact, we didn't even know it existed until we brought white sturgeon into captivity." The class of iridoviruses is well-known, however; this group causes disease in a wide range of insects and cold-blooded vertebrates.

Hedrick and his Sea Grant trainees, Charles Lee and Michael Ericson, showed that WSIV is transmitted through the water and infects gills, skin, and other tissues that come in direct water contact. Infected animals become lethargic and sink to the bottom, cease to feed, and waste away. Mortality is high, although some fish do fight off the disease and become resistant to subsequent infection.

Since there is no way to treat WSIV, the only way to eliminate it is to isolate fish known to be free of the virus and use them as breeding stock. Thus, detection is key. But until now, determining whether an individual fish was infected involved a two- to three-week tissue-culture test, much too slow to be effective.

With California Sea Grant funding, Hedrick and his colleagues have developed tests that use monoclonal antibodies against WSIV to detect the virus in tissue samples from live fish. The procedure is both accurate and rapid (about 3 hours).

In one test, a glass slide with cells from the gill of a fish is bathed with a solution of anti-WSIV antibodies obtained from mice or rabbits immunized with the virus. If the fish cells contain the virus, some of the antibodies bind and, when stained, fluoresce brightly under a microscope. In contrast, virus-free cells, which don't bind antibody, do not glow. Another, more sensitive antibody test is also nearly ready for field use.

With this tool, it may be possible to establish virus-free breeding populations of sturgeon.

"These tests," says Hedrick, "will allow for routine testing of both captive fish and newly caught fish." In addition to allowing culturists to establish WSIV-free stock, the tests will ensure that farm-reared fish returned to the rivers to replenish native populations will be free of the virus.

The reagents developed in these studies have been distributed to the fish health laboratories of several private companies and to resource agencies in California, Idaho, and Oregon.

Detecting Harmful Bacteria in Coastal Waters

As a means of protecting the health of swimmers, surfers, and others who enjoy the ocean, today's tests for bacterial contaminants are dangerously slow and woefully inadequate.

At present, government agencies that monitor water quality rely on a standard "indicator" species to check for hazardous levels of bacterial contamination resulting from sewage and other sources. Rather than measuring the levels of each bacterium present, this test checks only for one designated "indicator" organism (e.g., fecal coliforms). If the level of the indicator species is high, then bacterial and viral levels overall are assumed to be high and the water unsafe.

"Current monitoring techniques do not detect most types of bacteria in coastal waters, natural or introduced, and they're unacceptably slow," asserts Dr. Clifford Brunk of UC Los Angeles.

Frustrated with the limitations of present testing methods, Brunk and his colleague, Dr. David Chapman of UC Santa Barbara, turned to DNA technology for more accurate approaches. The procedures they developed with support from California Sea Grant are based on the unique genetic signature of each kind of bacteria. Using their new techniques, they can identify all the microorganisms in a sample, and do so quickly.

Their process involves extracting small amounts of bacterial genetic material from seawater samples and multiplying it millions of times, using a process called PCR (for polymerase chain reaction). The resulting genetic soup is then sorted and the types and amounts of bacterial species present identified.

Before you can identify bacteria that come from sewage spills or surface water runoff, however, you need to know what's naturally there.

By examining water samples from around Santa Monica Bay, Brunk and Chapman have discovered that each sample has only a few dominant bacterial groups; usually one or two predominant taxa represent 30 to 50 percent of species present. "This approach will, for the first time, allow us to generate an accurate map of naturally occurring bacteria in the coastal waters," says Chapman. Ultimately, it may also allow those monitoring the water to know when contaminating species have been introduced.

The researchers have developed characteristic profiles of the bay water at different times of the year for different locations. These profiles are stored as computer files, and each can be readily compared with any other profile to determine changes in and sources of bacterial populations.

Brunk and Chapman, with Dr. Jinliang Li and Sea Grant trainees Erik Avaniss-Aghajani and Gary Fogel, have tested the reliability of their new technology in cooperation with the Los Angeles City Hyperion Sewage Treatment Facility and the Orange County Sanitation District.

Their results indicate that the approach is versatile and can be applied both to field and clinical studies. As costs for the new molecular procedures come down, the scientists are optimistic that this approach will prove feasible for public agencies.

Avaniss-Aghajani, who completed his Ph.D. as a Sea Grant trainee on this project, is well aware of his role in disseminating the new technology. "I would never have had the experience of introducing new techniques to the scientific community if it hadn't been for my involvement in this project," he acknowledges.

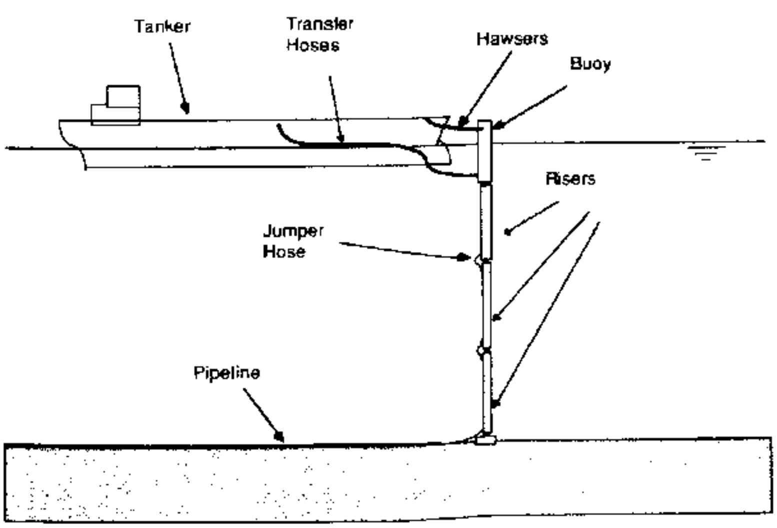
Moving Ports Out to Sea

Collisions and groundings are constant dangers to the tankers that deliver a billion barrels of crude oil to California's harbors each year.

One solution, identified by the U.S. Coast Guard as the least environmentally risky, would be to have tankers deliver their hazardous cargoes to deepwater "ports" constructed several miles offshore. The crude oil would be delivered from these structures to shore by pipeline. Not only could the tankers thus avoid shallow, congested waterways, but the possible impact of oil spills would be substantially reduced.

With support from California Sea Grant, two professors of engineering at UC Berkeley, Robert Bea and William Webster, investigated a type of deepwater port called the single-point mooring system (SPMS). Specifically, they evaluated the feasibility and reliability of different SPMS configurations for importing hazardous liquid cargoes to sites off Central and Southern California.

A type of deepwater port called a single-point mooring system, constructed several miles offshore, could reduce the environmental risks from tankers carrying hazardous liquids. In the design shown below, crude oil would flow from the tanker through a single buoyant riser to a pipeline on the seafloor.



> **"At costs that are comparable to inshore facilities, we have systems that are safer and more reliable for pollution control."**

Organizations providing assistance to the project included the California State Lands Commission, U.S. Minerals Management Service, U.S. Coast Guard, the Naval Civil Engineering Laboratory, Chevron Shipping Co., Chevron Petroleum Technology, Exxon Shipping Co., Louisiana Offshore Oil Port, and IMODCO.

Challenges were designing the moorings for use at depths of 1,000 feet, accounting for the severe ocean and earthquake conditions off California's coast, and berthing tankers up to 350,000 dead weight tonnage. An added, self-imposed restriction was that vessels should require no major modifications to use the offshore facilities.

With these constraints, only two designs proved viable. One consists of eight anchored legs arranged in a radial pattern around a large buoy. The other is a single anchor leg-mooring system, which has just one vertical buoyant riser through which the oil would flow to the pipeline (see figure). The "port" thus would be just a single buoy showing about 20 feet above the ocean's surface, plus a tender to help handle the mooring and discharge lines.

Bea and his Sea Grant trainee, Aaron Salancy, provided specifications for all the components that would support the mooring systems, including the tending vessels needed to assist the tanker and the pipeline that would transfer crude oil along the ocean floor to shore.

Bea and Salancy also investigated the likelihood of natural events of different magnitudes, including storm winds, waves, and earthquakes, and developed simple analytical models of how the two types of ports would respond. Meanwhile, Webster and his Sea Grant trainee, Wei Ma, worked on a model to predict how mooring lines would move in response to environmental forces in the ocean.

The models the two teams developed helped to specify several important design features—for example, how much tension would be needed in the anchor legs to hold the moorings in place.

Two questions remained: How reliable would the deepwater ports be, and how feasible would it be to build and operate them? The researchers were pleased to find that, according to their guidelines for design and operation, both port configurations would be at least as reliable as the crude oil import methods already in use. And the start-up and operating costs proved comparable to those of other oil-delivery systems.

Bea and Salancy have a slight preference for the eight-legged design, because it permits greater control over risks. "But either way, we get a bonus," Bea sums up. "At costs that are comparable to inshore facilities, we have systems that are safer and more reliable for pollution control."

Advanced Strategies for Increasing Abalone Growth

A common and persistent problem in marine aquaculture is rate of growth. Many desirable species of finfish and shellfish take so long to reach marketable size that it is difficult to produce them profitably. One species for which this is particularly true is the red abalone, *Haliotis rufescens*, a slow-growing species that forms the basis for a small abalone aquaculture industry in California.

In the wild, red abalone typically require four years to reach minimum marketable size. Since they take at least three years to attain sexual maturity, selective breeding for faster growth and other advantageous traits is a very costly and long-term process. Fortunately, a number of recent developments in modern molecular biology and biotechnology can provide the necessary technology to speed the growth of abalone.

To accomplish this goal, California Sea Grant has funded a project based on the observation that growth hormone can accelerate the growth rate and maturation of abalone. Additional funding has been provided by the California Competitive Technology Office.

One very direct strategy for enhancing abalone growth is to increase the number of abalone growth hormone genes. This can be accomplished by producing strains of abalone with either extra growth hormone genes or with an entire extra set of chromosomes. This dual strategy has been successfully applied by Dr. Dennis A. Powers at the Hopkins Marine Station of Stanford University, and his Sea Grant trainees, Terry Nicholson and Patricia Schulte.

The first approach involves the tools of molecular biology and genetic engineering. Transferring genes into fertilized eggs is a well-established, though difficult, procedure. In order for these newly introduced genes to produce a gene product like growth hormone, they must be attached to a region of DNA called a promoter, which directs the tissue in which the gene will be expressed as well as the timing and level of gene product that will be produced.

Powers and his group transferred combinations of different promoters with a growth hormone gene into the fertilized larvae of red abalone and tested them for both gene activity and accelerated growth. Promoters from viruses, microorganisms, and even fruit flies were tried, but none worked as well as a new promoter that they isolated from the abalone itself. This combination produces strains of abalone that grow between 40 percent and 100 percent faster than normal animals.

But gene transfer is not the only way to get an organism with enhanced growth. Powers and his colleagues have also produced abalone with an entire extra set of chromosomes; these are called triploids. Such abalone not only have an extra copy of the growth hormone gene, they have an extra copy of every other abalone gene, including all the growth-promoting genes.

Powers and his group were able to produce a triploid strain of red abalone that grows twice as fast as normal (diploid) animals. Triploid animals are sometimes sterile: they cannot self-perpetuate. In the event that triploid abalone prove to be sterile, this will not preclude their use in aquaculture because Powers and his colleagues have also produced tetraploid abalone, which when reproductive can be bred with normal diploid animals to produce millions of triploid abalone. Alternatively, chemical treatment and artificial fertilization of large numbers of eggs can be used to produce triploids.

The abalone research has been so successful that Stanford University has filed two patents on this work.

Powers has collaborated extensively with French colleagues to apply the gene transfer techniques to other shellfish, and several California and Asian mariculture firms have expressed interest in applying

Powers' novel technologies to the commercial production of abalone and other shellfish. And, SeaGenes, Inc., a small California biotechnology company, is helping to transfer this novel technology from Stanford University to these various California and Asian companies.

The trainees have profited, too. Says Schulte, who was recently awarded her Ph.D., "I have benefited from direct contact with leading scientists in a variety of fields as well as access to the latest equipment and techniques in molecular biology. I feel that I have been exposed to the best of both the practical and theoretical aspects of biological research."

Speeding Abalone's Rate of Growth: A Different Approach

Introducing extra genes into an organism is not the only way to enhance its rate of growth. Nor are growth hormone genes the only ones that are important. Rate of growth is an extremely complex metabolic process involving the action of many genes and functions.

For example, one extremely important process is nutrient conversion, the efficiency with which an animal transforms the food it eats into flesh. Food conversion, too, is controlled by many different genes, but it is also influenced by environmental factors and chemicals that can activate certain genes and enhance their effectiveness.

This concept forms the rationale behind a second Sea Grant project aimed at accelerating the growth of abalone. Dr. Daniel E. Morse at UC Santa Barbara headed a project to identify some of the genes that are critically important in the food-conversion process and to devise ways to enhance the activity of these genes.

He and his colleagues, including Sea Grant trainee David Nees, found two genes that appear to significantly influence the rate of growth. One gene produces the major muscle protein tropomyosin; the other, a vital digestive enzyme called chymotrypsin. This enzyme breaks down proteins in food and thus supplies essential raw materials that can be converted to energy and built up into new abalone proteins. The gene is especially active in the early larval stages and is essential for rapid growth.

Perhaps most significantly, Morse's group discovered a "genetic switch" that governs the dramatic change-over in expression from the chymotrypsin genes that are expressed in the larva to those expressed in the young juvenile as soon as growth begins. Their research suggests that the time at which this switch is activated may directly control early growth rate.

Their work indicates two possible ways to enhance growth rate of abalone. One approach would be to feed abalone larvae with protein—milk products, for example—that are particularly susceptible to the action of this enzyme, thereby ensuring high nutrition. Also, if the gene is under the control of a genetic switch, it may be possible to manipulate the gene so that it remains highly active throughout life.

Morse and his group are continuing their basic research on growth control, and, in close collaboration with California abalone aquaculture firms, are investigating the effects of specific diets on the regulation of this genetic switch, the timing of its activation, and resulting effects on abalone growth rate and size differences.

The Planktonic Odyssey of Larvae

Finding management solutions to dramatic population declines in marine animals like sea urchins and crabs is hampered by our lack of understanding of these animals' life histories.

In the case of sea urchins, whose density in Northern California has dropped to about one-fourth what it was in 1988, proposed management strategies involve closing areas to harvest, either temporarily or permanently, so populations can recover from fishing pressure. The rationale is that reserves, refuges, and other protected areas serve as "source areas" from which drifting planktonic larvae could disperse to renew adjacent areas.

The planktonic forms are only weak swimmers whose larval odysseys are controlled by ocean circulation. Little is known about how far larvae travel in surface currents, so it is uncertain precisely where or how close together reserves would need to be to effectively repopulate fished areas.

Then, too, many fishermen and processors reject fishing as the cause of observed declines, and believe, instead, that natural conditions underlie the ebb and flow of populations.

With support from California Sea Grant, Professors Louis Botsford and James Quinn of the UC Davis Bodega Marine Laboratory, with their associate Dr. Steve Wing, are using both computer modeling and extensive field studies to investigate the dispersal of larval sea urchins and crabs in Northern California. They are also studying variability in urchin growth and mortality rates along the coast. Working with them is a research oceanographer, Dr. John Largier of Scripps Institution of Oceanography.

The scientists are assisted by their Sea Grant graduate trainees, Lance Morgan, Carolyn Lundquist, and Jennifer Diehl, as well as a large number of cooperating organizations.

The question that the scientists are asking is fundamental: "We know that the settlement of crab and urchin larvae is very variable from one place to another and from one time to another," notes Botsford. "We want to understand why."

To conduct their research, the Sea Grant scientists first needed to organize an extensive sampling program utilizing both ships and shore stations, and extending over several years. Cooperating with them in this project was the California Department of Fish and Game, the Gulf of the Farallones National Marine Sanctuary, the National Marine Fisheries Service, Scripps Institution of Oceanography, Pt. Reyes Bird Observatory, Oregon State University, and the Pacific Fisheries Environmental Group.

What the researchers have discovered is that during periods of upwelling, invertebrate larvae accumulate in the warm water that collects between the Farallon Islands and Pt. Reyes, for example, and in the upwelling "shadows" of other capes and headlands. Then, when the southerly winds that cause upwelling abate, this larvae-rich water moves north in coastally trapped currents, and larvae settle along the coast. Larval settlement becomes more episodic and less frequent with increasing northward movement away from the accumulation zone for an embayment.

Weekly variability in upwelling leads to differences in annual settlement along the coast: Nearly twice as many crab larvae settle at Pt. Reyes and to the south, where warmer water is constantly present, than do to the north, where settlement occurs only when upwelling winds relax and warm-water currents move north. The scientists have found that urchins, too, settle during specific oceanic conditions, but less predictably than crabs.

In addition, their research suggests that larval dispersal from any subpopulation of adult animals may be limited to the

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length of an embayment—for example, Pt. Reyes to Pt. Arena, and Pt. Arena to Cape Mendocino. "That's because there are strong seaward currents at headlands, which would sweep the larvae out to sea," Largier explains.

When this information is incorporated into computer-modeling studies, the results suggest that closures at those locations where the production of larvae is particularly high may indeed sustain population levels over much larger areas, even in the face of heavy fishing pressure.

"This work begins to provide the sound scientific understanding necessary to underpin management decisions," Botsford observes.

Conserving Genetic Diversity in Eelgrass

Good intentions may not be enough when it comes to protecting important species.

Eelgrass provides a case in point. Although eelgrass beds are important for stabilizing shorelines, providing fish habitat, and filtering pollutants and nutrients, they are being lost at an accelerating rate.

It is true that eelgrass is being transplanted to new sites in order to mitigate for habitat modification or loss. But these efforts are expensive, easily exceeding twenty-five thousand dollars per acre, and too often unsuccessful. Some estimates put the survival rate of pilot transplantations at less than 50 percent.

With support from California Sea Grant, Dr. Susan Williams of San Diego State University, with her Sea Grant trainees Christopher Davis, Patrick Ewanchuk, and Amy Sewell, have begun looking at one factor that may affect transplantation success—whether plants used in constructing sites have sufficient genetic diversity for new populations to persist.

At present, transplants are often selected from nearby sources. Because seagrasses are clonal plants and propagate well vegetatively, donor plants may thus come from a single genetic stock.

"When we talk about preserving biodiversity, we must understand that this includes the richness of the gene pool within a species, as well as the diversity of species and ecosystems," Williams says. Low genetic diversity may contribute to the inability of populations to respond to environmental changes over time and to their eventual loss, she believes.

In order to determine genetic richness in pristine beds, Dr. Williams and her students collected leaf shoots from sites at San Quintin Bay in Baja California, and used five indices to assess the shoots'

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genetic diversity. The results were then compared statistically with those from eelgrass sites in San Diego County, some which were natural urban beds and some of which were transplanted.

The results showed that, for each index, eelgrass from Baja California had by far the greatest genetic diversity. Next came natural beds in San Diego County (South San Diego Bay and Silver Strand), though these were low in diversity compared to the Baja plants. The lowest genetic variation was found in transplanted beds (North Island and Sail Bay).

Two surprises were that larger transplanted beds did not show more genetic diversity than smaller sites (although larger natural beds contained more genetic diversity than smaller ones), nor did older transplanted beds over younger ones.

In the experimental phase of her work, which compared the transplantation success of groups of plants with high and low genetic diversity, she observed that the high-diversity groups produced leaf shoots at a significantly higher rate and had a higher average rate of increase per month. In addition, she found genetic variation in the high-diversity groups remained relatively constant over time, while that in the low-diversity groups declined.

Although Williams regards her experimental work as preliminary, it does suggest that those beds with relatively high genetic diversity should be given a high priority for conservation.

In addition to a number of environmental consulting firms, cooperators in this project have included the National Marine Fisheries Service, California Department of Fish & Game, U.S. Navy, and the City of San Diego.

Colleagues from the Centro de Investigaciones Científica y de Educación Superior de Ensenada helped to select pristine sites in Mexico, and will use data provided by Williams as a benchmark against which changes over time can be measured.

Preliminary results from this project have led to the development of a complementary project by NOAA's Coastal Ocean Program.

A Commitment to the Future

Virtually all of the research projects supported by California Sea Grant involve at least one student trainee, who works alongside a Sea Grant scientist while completing a marine-related graduate degree. Over the years, this traineeship program has become a major source of scientific, management, and industry talent. Since its inception, California Sea Grant has supported nearly 900 graduate students in fields as diverse as oceanography, ecology, engineering, law, and food science.

In addition to supporting graduate education through its trainee program, California Sea Grant sponsors a number of other educational opportunities.

California Sea Grant is also keenly aware of the need for scientifically-trained policymakers to address the increasing number of coastal conflicts caused by the growth in population along our shorelines, and who understand the changing roles played by science, research, and resource management in marine and coastal issues. To increase the bridges between science and policy, California Sea Grant offers two fellowship experiences: the John A. Knauss National Sea Grant Fellowship and the California State Fellowship Program.

Each year, Sea Grant programs around the nation nominate graduate students for the Knauss Fellowship. This program matches graduate students who have demonstrated interest both in ocean policy and marine science with government "hosts" in Washington, D.C. The California Sea Grant College System has been honored to have nine nominees selected as fellows between 1991 and 1996. They are: Anne Petrenko and Lisa Dilling, Office of Global Programs, NOAA; Aaron King, Subcommittee on Environment—Committee on Science, Space, and Technology; Alessandra Conversi, Ocean Science Research, National Science Foundation; David Wilmot, Ocean Studies Board, National Research Council; Thomas Boyd, Division of Ocean Sciences, National Science Foundation; Christopher Carr, Office of Fisheries Affairs, U.S. Department of State; Erik Schmidt, U.S. Fish and Wildlife Service; and Debbie Colbert, House Committee on Resources, Subcommittee on Fish, Wildlife and Oceans.

In 1987, California Sea Grant Collge System initiated a State Fellowship Program modeled on the national program. Fellows between 1991 and 1996 have been: Linda Rao, Phillip Giovannini, and Shannon Erickson, Joint Committee on Fisheries and Aquaculture; Susan Reidy and Mark Evans, Pacific Fisheries Legislative Task Force; Rob Pollard, Melody Tate, Chris Davis, and Chris Potter, Senate Committee on Natural Resources and Wildlife; Linda Martello, California Coastal Commission; Stephen Clark, California Regional Water Quality Control Board; Chris Parta and Christopher Chauncey, Subcommittee for River Protection and Restoration; and Richard Green, Monterey Bay National Marine Sanctuary.

The California Sea Grant College System also awards a four-year college scholarship each year to a high school senior who shows a particular aptitude in marine science. Winners of the John D. Isaacs Memorial Scholarship from 1991 to 1996 have been Rose Gregory, who continued her studies at San Francisco State University; Kenia Whitehead, University of California, San Diego; Bryan White and Kimberly Johnson, Stanford University; Lulu Wang, Pomona College; and Misty Rose Borja, California State University, Long Beach.

California Sea Grant also supports the development of K–12 educational activities at the University of California, Los Angeles, including its new Ocean Discovery Center.

Sea Grant Extension Program

Part of Sea Grant's mission is to move the results of marine research out of the universities and into the hands of people who use or manage coastal and ocean resources. At the same time, university scientists need to be made aware of the marine-related information needs of industry, government, and the public.

California Sea Grant's primary arm for achieving this two-way linking function is its Sea Grant Extension Program. Administratively housed within the University of California Cooperative Extension, the program utilizes the talents and expertise of two technical specialists and seven area advisers to conduct research on highly targeted problems and to provide information and advice to a wide variety of constituents.

TECHNICAL SPECIALISTS

Marine Fisheries
Christopher M. Dewees
University of California, Davis

Christopher Dewees, who coordinates the Sea Grant Extension Program, has served as the statewide Marine Fisheries Specialist since 1972. In recent years, he has focused research and education activities on fisheries management issues, such as limited entry, individual transferable quotas (ITQs), technology development, and salmon issues.

Dewees recently completed studies of the socioeconomic effects of ITQs in British Columbia and New Zealand, with the aim of helping U.S. policy makers and others better understand this management technique. He serves on the California Salmon Marketing Council and the Department of Fish and Game Director's Sea Urchin Advisory Committee. As coordinator of California Sea Grant's Extension Program, he provides programmatic support to the statewide network of marine advisors.

Seafood Technology
Robert J. Price
University of California, Davis

Seafood Technology Specialist Robert Price works to improve the quality and safety of seafood available to consumers. He is also concerned with increasing the use of modern technology in seafood processing, handling, and waste management. Price conducts numerous workshops and short courses on seafood quality and safety each year for processors, retailers, and commercial laboratories. He has been particularly active in educating industry members to the new federally mandated Hazard Analysis Critical Control Point (HACCP) system, which ensures seafood safety by identifying and controlling critical steps in food processing, and serves on the steering committee for the national Seafood HACCP Alliance. Price has also written a number of consumer information leaflets addressing seafood quality and safety, which are available at a Seafood Network Information Center (SNIC)* that he maintains on the Web. An internet mailbox has been initiated to facilitate information exchange on seafood safety and the Seafood HACCP Alliance.

*http://www-seafood.ucdavis.edu

SEA GRANT MARINE ADVISORS

Del Norte and Curry Counties
James B. Waldvogel
Crescent City, California

Jim Waldvogel conducts the marine advisory program in the northernmost California county (Del Norte) and the southernmost Oregon county (Curry), areas that are deeply impacted by salmon fishery issues. He recently completed the 15th season of a 20-year research study on chinook salmon spawning escapement in the Smith River. He has also conducted studies on sportsfishers' use of the Chetco and Smith rivers, and a survey of ocean sport salmon fishers in the Klamath Management Zone. In addition, Waldvogel has conducted projects in marine safety training for the commercial fishing industry and on how fishing families are adapting to change. He has been active in watershed habitat enhancement, and serves as chairman of the Smith River Advisory Council and as technical team member to the Klamath Management Council, the Klamath River Task Force, Curry County watershed councils, and the Klamath Management Zone Coalition.

Humboldt and Mendocino Counties
Susan McBride
Eureka, California

Susan McBride is the Marine Advisor for Humboldt and Mendocino counties. Her program reflects the diverse marine resource issues in the two counties. On the Humboldt Bay waterfront, she works with a coalition of fishing industry representatives, aquaculturists, business owners, historians, and artists to revitalize publicly owned structures into multiuse facilities. She organizes workshops on abalone aquaculture and fisheries issues, and works to educate the public on the biological and socioeconomic value of area estuaries. McBride recently participated in a large collaborative study of California halibut in Humboldt Bay, which resulted in needed information on the fish's age, diet, and reproductive status. She conducted feeding trials with red sea urchins, which have shown that this valuable fishery resource can be held and grown in land-based aquaculture systems. On behalf of California Sea Grant, which will sponsor the event, she is helping to organize the Third International Abalone Symposium, set for October 1997 in Monterey, California.

Marin and Sonoma Counties
Paul Olin
Santa Rosa, California

As the Sea Grant Marine Advisor for Marin and Sonoma counties, Paul Olin is active with projects in aquaculture, recreational and commercial fisheries, and watershed management. He is investigating environmental and management factors related to oyster mortality in Tomales Bay. He is also evaluating artificial diets for red abalone culture and exploring the feasibility of enhancing the commercial value of red sea urchins through supplemental feeding. Working with the commercial passenger fishing fleet, Olin is monitoring fish quality in refrigerated and unrefrigerated holding systems and assessing anglers' attitudes regarding the two systems. To develop a better understanding of halibut populations in the area from Bodega Bay to San Francisco Bay, he is cooperating in a tagging program with the Department of Fish and Game, and commercial and recreational fishermen. He also works with local watershed groups and agricultural landowners to improve fish habitat and water quality throughout the coastal region. Olin and Advisor Jodi Cassell recently turned their attention to the impact of aggressive introduced species on California ecosystems, and organized a Sea Grant workshop to identify needed research on this issue.

San Francisco Bay Counties
Jodi Cassell
San Bruno, California

Jodi Cassell is the Marine Advisor for San Francisco and San Mateo counties. Her research and program interests include watershed management, coastal and marine tourism and recreation, estuarine ecology, and seafood safety. She is working with local teachers and watershed groups to facilitate school group and public involvement in stream monitoring and restoration in San Mateo County, as a means of improving steelhead habitat and awareness of anadromous fish habitat issues. In cooperation with the Monterey Bay National Marine Sanctuary and local nonprofits, she organizes a quarterly lecture and discussion series about resource and management issues for coastal San Mateo County and the Sanctuary. She is also working with faculty from San Francisco State University to initiate a study of coastal/marine tourism and recreation opportunities and constraints in San Mateo County. In cooperation with Advisor Paul Olin, Cassell is working to provide programs and evaluate research needs related to nonindigenous marine organisms in California. She recently received a special grant from the U.S. Fish and Wildlife Service to initiate a pilot education project for California boaters on zebra mussels; ultimately, she hopes to extend this program to the Pacific Northwest states as well. She also is working with local nonprofits and agency representatives to develop public outreach materials for subsistence fishermen on contaminants in San Francisco Bay fish.

Monterey and Santa Cruz Counties
Richard M. Starr
Moss Landing, California

Rick Starr is the Marine Advisor for Santa Cruz and Monterey counties. His program reflects the Monterey Bay area's focus on education, research, and conservation. He has been an active participant in the development of the Monterey Bay National Marine Sanctuary, and has created and distributed educational materials related to marine resources in the Sanctuary. For example, he has helped film wildlife documentaries for public television on sea otters and gray whales, and has written educational brochures for boaters, kayakers, and divers using the reserve. Starr assists with coordinating activities of the many marine research organizations in the Monterey Bay region. He serves on a number of research advisory committees and has been a primary organizer of the Monterey Bay Research Symposium for the last three years. Starr provides technical advice and training in the use of geographic information systems (GIS) to help businesses, resource users, environmental organizations, and governmental agencies coordinate water quality and coastal resource management plans. His current fisheries research relates to studying how the movements of rockfishes influence the effectiveness of new fishery management tools, such as harvest refugia.

San Luis Obispo, Santa Barbara, and Ventura Counties
Deborah McArdle
Santa Barbara, California

Deborah McArdle, the Marine Advisor for Santa Barbara and San Luis Obispo counties, is active with projects in recreational and commercial fisheries and the transfer of information through new technology. She is also currently researching alternative management strategies, including Marine Protected Areas (MPAs). California MPAs have historically been designated on a case-by-case basis, causing information about them to be confusing and complex. MPAs in California are also listed under numerous classifications, ranging from small, highly protected reserves to larger, multiple-use sanctuaries. One objective of her project is to create a publication that will provide researchers, managers, and resource users with comprehensive information on the purposes, locations, and regulations of all California MPAs. Advances in computer technology can be of benefit to the marine community. Through her program, McArdle has attempted to assist members of the fishing industry in locating and obtaining information on the internet by holding workshops and by developing a California Fisheries Information Home Page**. In addition, she provides a wide variety of information to aquaculturists, educators, government, and the general public.

One objective of her program is to create a publication that will provide comprehensive information on all California MPAs.

San Diego, Los Angeles, and Orange Counties
Leigh Taylor Johnson
San Diego, California

The Sea Grant Marine Advisor in San Diego County, Leigh Johnson, focuses on coastal water-quality management and improvement. Using consensual decision-making processes, she assisted local groups in preparing recommendations for preventing boating-related pollution and provided them to the California Technical Advisory Committee on nonpoint-source pollution from marinas and recreational boating. She is educating boaters and boating businesses on pollution prevention and cochairs the California Clean Boating Network of educators and businesses. Last year, she organized seminars on pollution prevention for nearly 100 marina managers and boatyard operators throughout California. Johnson also represents Sea Grant on the San Diego Interagency Water Quality Panel. This consortium of government, business, environmental, scientific, and recreational interests is preparing a comprehensive water-quality management plan for San Diego Bay. Johnson chairs the Panel's Communication and Education Committee and serves on several others. In addition, she provides information to anglers, aquaculturists, educators, government, and the public.

**http://www.calpoly.edu/~jstannar

California's Sea Grant Institutions

Since 1968, Sea Grant in California has supported a unique combination of marine research, education, and advisory activities at a number of California universities and colleges. These institutions have included:

Bodega Marine Laboratory
California Institute of Technology
California Polytechnic University
California State University, Fresno
California State University, Hayward
California State University, Long Beach
California State University, Los Angeles
California State University, Northridge
Claremont College
Hopkins Marine Station
Humboldt State University
Moss Landing Marine Laboratories
Occidental College
San Diego State University
San Francisco State University
San Jose State University
Southern California Ocean Studies Consortium
Stanford University
University of California, Berkeley
University of California, Davis
University of California, Irvine
University of California, Los Angeles
University of California, Riverside
University of California, San Diego
University of California, San Francisco
University of California, Santa Barbara
University of California, Santa Cruz
University of San Diego
University of Southern California