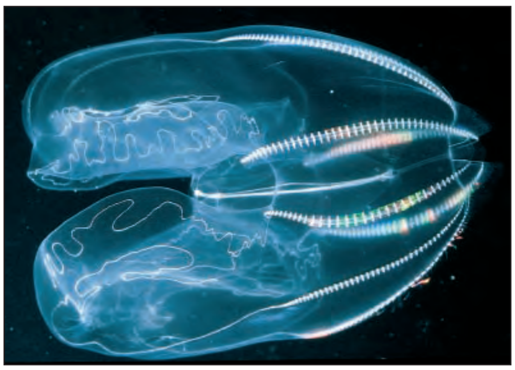
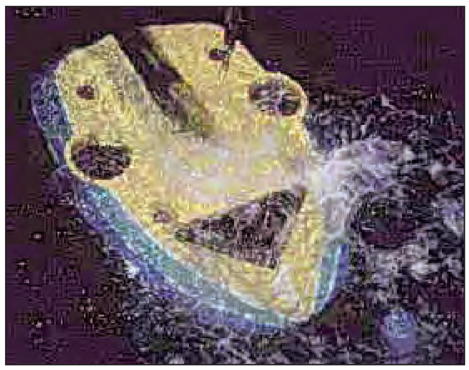
MONTEREY BAY AQUARIUM RESEARCH INSTITUTE

MBARI's First Decade: A Retrospective





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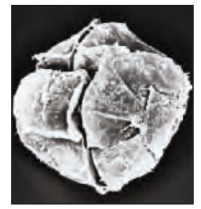
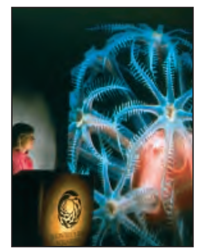




courtesy of Monterey Bay Aquarium

The Monterey Bay Aquarium Research Institute grew out of an exploratory voyage, a meeting of minds, and a vision.

(top) In September 1985 Bruce Robison made 55 dives to the depths of Monterey Bay in the submersible Deep Rover.

(bottom) The ribbonfish, Trachipterus altivelis.

Aerial view shows Monterey Harbor and Monterey Bay to the north.

The exploratory voyage spanned a series of submersible dives by biological oceanographer Bruce Robison. It was 1985, and Robison, then on the faculty at the University of California, Santa Barbara, had a research grant to use the human-occupied submersible *Deep Rover* to investigate the depths off the Central California coast. What he observed through the submersible's acrylic sphere both excited and frustrated him. The excitement stemmed from the remarkable animals and environment he witnessed; the frustration came from not being able to document his findings well due to the lack of a high-quality video camera.

Fortunately, Robison found a solution at the newly established Monterey Bay Aquarium, where engineer Derek Baylis had designed and constructed an underwater housing for a broadcast-quality camera. Mounted on *Deep Rover*, the camera allowed Robison to capture images of the wonders he'd been trying to communicate to skeptics.

The captivating video images from Robison's exploratory voyage inspired the concept of a deep-water research program in Monterey Bay. While aquarium planners had intended to cultivate research projects related to marine life displays, aquarium benefactor David Packard's thinking now shifted to the idea of establishing a research program with a much broader agenda.

In autumn of 1986 a meeting was called to convene an oceanographic think-tank of scientists from top-flight West Coast research institutions. The group discussed the status of oceanography and the feasibility of setting up a major research effort at Monterey Bay. A planning committee was formed, composed of Chair Tjeerd van Andel, David Epel, and Craig Heller, all from Stanford University; G. Ross Heath of the University of Washington; and George Somero and Walter Munk with Scripps Institution of Oceanography. Meeting with David Packard, his wife,

David Packard was founder of MBARI and chairman of the board of directors from 1987 until his death in 1996.

Lucile, and members of the aquarium board, the core group began to set goals and parameters for a research center. The new institute was to have, in the words of the committee, "a clear identity distinct from that of other oceanographic institutions and a reason for being that leaves no doubt that the institute occupies a mostly vacant niche of importance." In 1987 Packard decided that the research center should be an independent entity, separate from the aquarium. Articles of incorporation as a public-benefit, non-profit corporation were filed in May, and the MBARI (pronounced "em-bar-ee") board of directors met for the first time on June 27.

The institute's "clear identity and reason for being" derived directly from David Packard's vision. A former U.S. under-secretary of defense, Packard was keenly aware that, with the exception of the undersea wanderings of *Alvin*, most previous investigations with human-occupied submersibles had been limited to depths of 600 meters (2,000 feet) or less and used for specialized purposes such as U.S. Navy and oil-industry operations. Packard realized that Monterey Bay—with its steep drop-off to near-abyssal depths within 100 kilometers (60 miles) of shore—offered an unprecedented opportunity to explore, in microcosm, the planet's oceans. And, he realized that development of improved technology for observation of the deep ocean would offer great opportunity for scientific advances. It was also a unique chance for Packard to apply his energy, leadership, and engineering acumen to press oceanography onward into twenty-first-century technology.

A key advisor to Packard in the founding of MBARI was aquarium board member and chemical oceanographer John Martin. As a highly respected scientist and director of California State University's Moss Landing Marine Laboratories, Martin was in a unique position to provide valuable information on the politics and practicalities of setting up a research institute. He stood strongly for scientific collaboration, and he reinforced many aspects of Packard's vision for the institute and a long-term view of Monterey Bay as a site for world-class oceanography. As a member of MBARI's board of directors from 1987 until his death in 1993, Martin's influence was a powerful force in the institute's early years.

Don't be afraid to make mistakes; if you don't make mistakes, you're not reaching far enough.

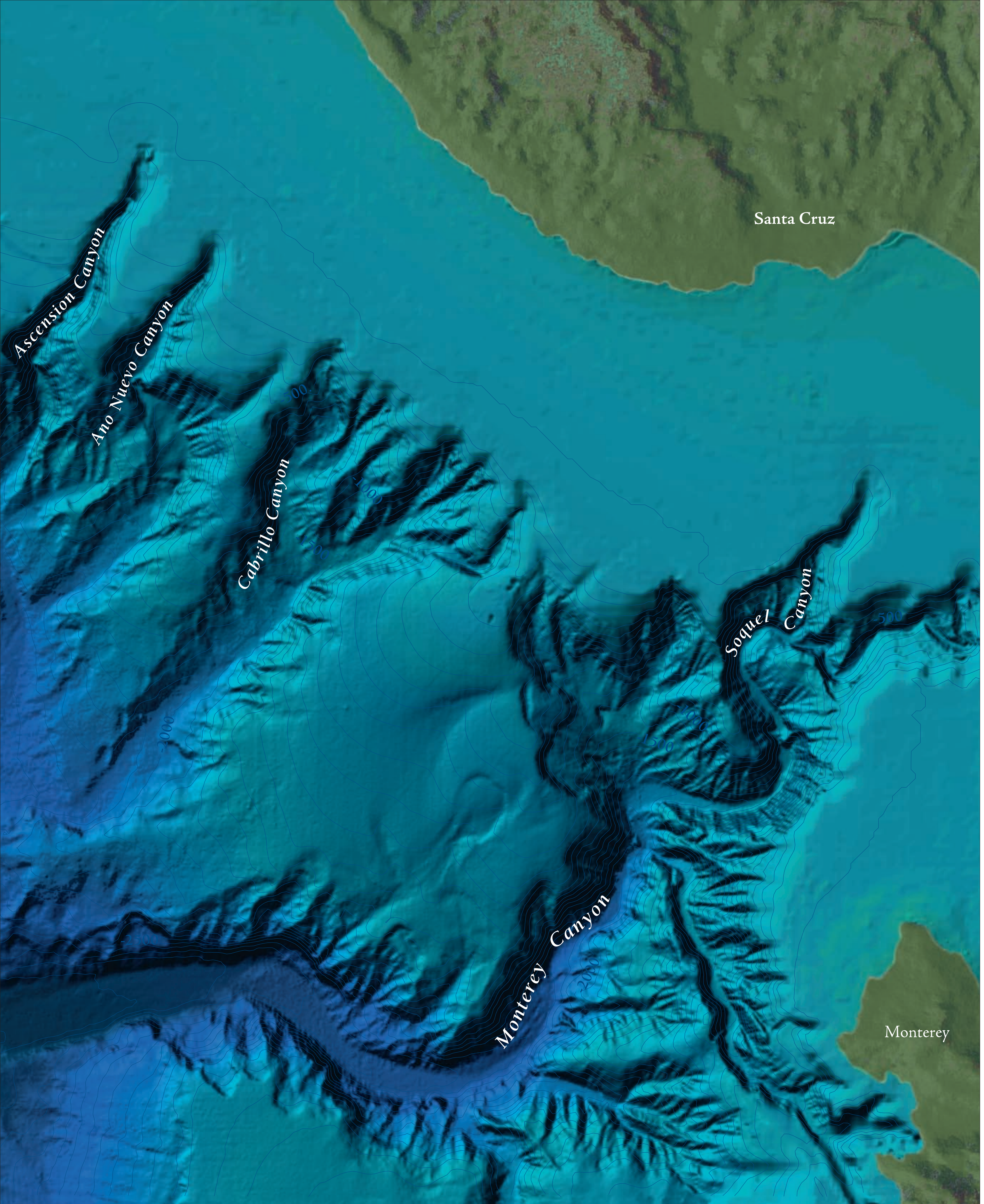
Packard recognized three areas of nascent technology that made his vision for a major ocean-research program particularly timely: remotely operated underwater vehicles (ROVs), instrumentation for chemical analysis, and computer science and communications. All of these would become cornerstones in MBARI's research agenda.

Equally important to the institute's overall direction were issues of management. Cognizant that scientific progress crucially depends on the development of instrumentation and equipment, Packard insisted that scientists, engineers, and operations staff work together in close collaboration. From the outset he advised that institute scientists should pose the research questions, engineers devise instruments and equipment for the pursuit of scientific knowledge, and operations staff focus on effective operation of the institute's experimental technology. This management goal—the dynamic and ever-challenging three-way marriage of science, engineering, and operations—remains one of MBARI's chief distinguishing features.

The final critical ingredient in Packard's vision for MBARI was the matter of funding. He had witnessed first-hand the inefficiencies associated with federally funded research. His experience convinced him that MBARI could maximize its chances for success only if its researchers were freed from the burden of applying for external grants. So he provided the institute with start-up costs of about $13 million and continued funding through the David and Lucile Packard Foundation. In exchange he demanded excellence and innovation in developing "better equipment, instrumentation, systems, and methods for scientific research in the deep waters of the ocean."

Throughout the years until his death in 1996, Packard would express his vision in a host of less formal phrasings, the sentiments of which those who knew him remember well: Go deep. Stay long. Take risks. Ask big questions. Don't be afraid to make mistakes; if you don't make mistakes, you're not reaching far enough.

In this, the tenth anniversary year of MBARI's founding, David Packard's inspiration remains a guiding force at the institute. Though he is no longer physically present, the mission he espoused is very much intact.



Original map compiled by Norman Maher

Monterey Canyon bathymetry

First Blueprint, First Ocean Hardware

MBARI's first headquarters at 160 Central Avenue, Pacific Grove, California.

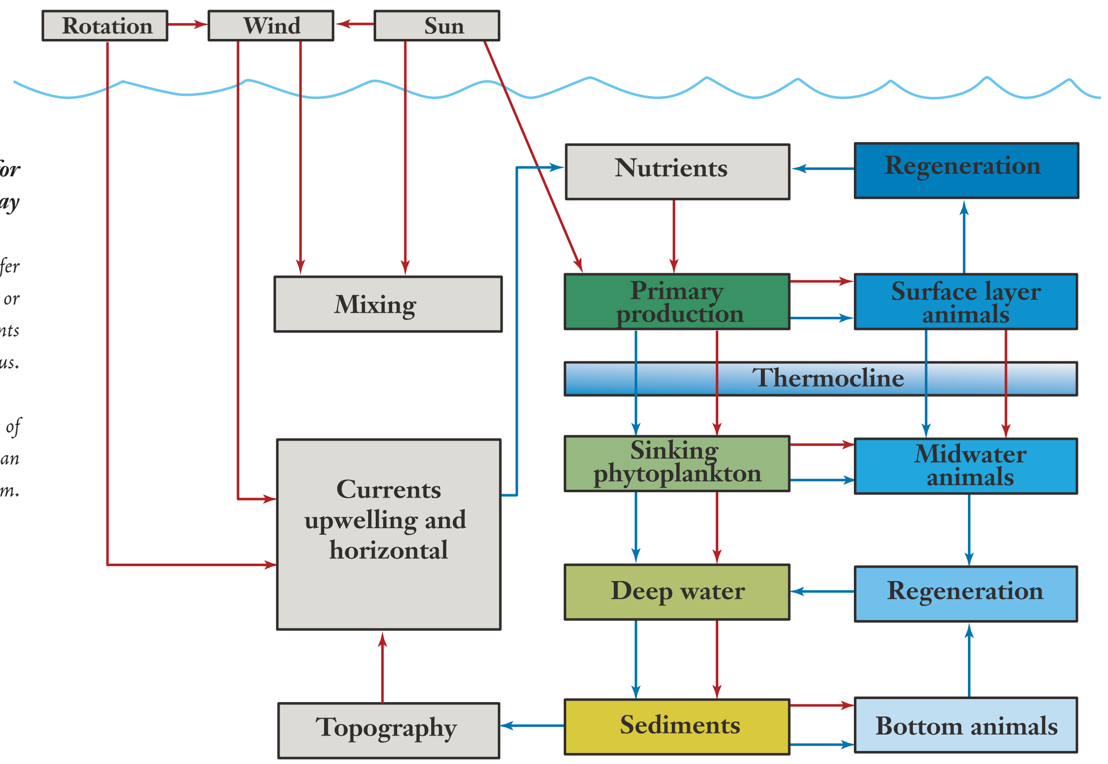
One of the first official decisions of MBARI's board of directors was to hire Richard Barber of Duke University to serve as the institute's executive director. The board also authorized the purchase of a headquarters for offices and labs at 160 Central Avenue, Pacific Grove. The doors opened in the fall of 1987 with five employees, and little by little the science and engineering staff grew. Barber immediately focused his attention on drawing up a broad research plan that would comply with the guidelines set by Packard, who more than once had expressed his desire that an understanding of the California Current be set as a goal for MBARI research.

For decades blue-water oceanography had prevailed in the allocation of oceanographic resources. It had always been difficult for coastal-water researchers to obtain ship time on big science vessels to investigate waters only a few kilometers from shore—and yet the coastal zone was arguably more variable and complex than the open ocean.

Like many oceanographers, Barber's perspective was systems-oriented, and he was strongly attracted to MBARI for the opportunity to address the gaps in oceanographic understanding of coastal systems. Many of the unanswered questions about coastal systems were, and are, related to the nature of physical, biological, and chemical relationships between system components:

- How do winds and solar radiation, which give rise to climate, affect currents and primary productivity, the growth of phytoplankton? What are the seasonal variations?
- What happens to the copious quantities of organic material produced by photosynthesizing algae in the sun-lit zone of the ocean?
- What animals make up the marine food webs? How big are their populations, and where are they distributed? How

How do winds and solar radiation, which give rise to climate, affect currents and primary productivity, the growth of phytoplankton? What are the seasonal variations?



System Concept for Monterey Bay

The blue lines show the transfer of mass as either the organic or inorganic forms of the elements carbon, nitrogen, and phosphorus.

The red lines show the transfer of energy or momentum in the ocean ecosystem.

do marine animals behave, survive, and relate to each other in communities?

- What factors influence the mixing of surface waters and drive the upwelling of cold, nutrient-rich waters from the depths? How is seawater chemistry linked to productivity?

- What geological processes occur in the depths? How do they affect living conditions for organisms? How do they alter ocean chemistry?

What geological processes occur in the depths? How do they affect living conditions for organisms? How do they alter ocean chemistry?

In pursuit of answers to such questions, MBARI's overarching goal became the development of a system concept for the ecology of Monterey Bay that could be expanded for use in other ocean regions and, eventually, for use on a global scale.

Another theme emerged in the *modus operandi* of the institute, again, under the leadership of MBARI's founder. In 1989 Packard noted "Deep-water research involves immense amounts of data. I have the impression that much more time is being spent in collecting the data than in looking at it and analyzing it. We believe that situation can be greatly improved."

What Packard had in mind was a continuation of the information revolution that he and other mid-century innovators had instigated with the development of computers. He was exasperated by the traditional approach to ocean science. How, he asked, could humans acquire a broad understanding of the ocean by periodically venturing out to sea to collect random samples, bring them back to land for analysis, and record the results? The key to improving human understanding of the 97 percent of Earth's living space represented by the deep sea was to send *instruments* to sea, not humans; to move *information*, not samples.

It became apparent in the following years that simultaneously tackling all the broad questions defined at MBARI's inception was less than practical. As the institute has evolved, projects have developed as sub-sets of the initial research outline, and topics of inquiry have spun off from the original scientific questions. Nonetheless, the institutional eye has remained fixed on the target of an integrated system concept. Pursuit of this goal has led MBARI through its first decade of discovery.

First Ocean Hardware

One of the first major tasks facing institute managers was the acquisition of the basic equipment for deep-sea exploration: a research vessel and a submersible.

For the research ship, Derek Baylis, who had joined the MBARI staff, went bargain hunting in offshore oil territory. He found the *M/V Lolita Chouest* listed for sale in Louisiana. Having spent its early years as a utility boat hauling drilling muds to offshore oil rigs, *Lolita* was out of a job due to a downturn in the oil industry. Baylis negotiated the purchase of the 33.5-meter-long (110-foot-long) boat and hired a captain and crew to make the 8,000-kilometer (5,000-mile) sea voyage back to California. After a month of boat repairs and a name change—to *Point Lobos*—the crew loaded on board supplies and a shotgun for protection in case they encountered pirates. Though pirates never materialized, the first MBARI ship's crew endured heavy seas and equipment failures as they navigated south, then west through the Panama Canal and up the West Coast to Monterey Bay.

(top) The M/V Lolita Chouest *was purchased by the institute in Louisiana in 1987.*

(bottom) The renamed vessel, R/V Point Lobos, *was converted into MBARI's first research ship.*

(top) Mark Chaffey and Chris Grech move the newly delivered ROV Ventana *into Pacific Grove headquarters in the winter of 1988.*

(bottom) Ventana *was placed aboard its mother ship, the* R/V Point Lobos*, later that year.*

Parked for months near the Monterey Coast Guard pier, *Point Lobos* underwent a metamorphosis. MBARI engineers and technicians removed the boat's sleeping quarters, upgraded its hydraulic system, and converted the forepeak into a science command headquarters with a bank of electronic consoles for controlling a remotely operated vehicle (ROV). Also installed were a science lab, sophisticated navigation and positioning instruments, a sub-deck machine shop, and deck cranes and equipment for handling an ROV and its tether. With a coat of blazing white paint, the transformation to oceanographic vessel was complete, and the *R/V Point Lobos* made its debut as a research support ship.

To locate a submersible partner for MBARI's first ship, David Packard sent Baylis to a trade show to see what undersea equipment was available commercially. This initial expedition led them to Vancouver, British Columbia, where International Submarine Engineering (ISE) built underwater robots for science, the military, and the oil industry. Packard had already determined that remotely operated vehicles (ROVs)—rather than human-occupied submersibles with their inherent risk to human life—were the underwater workhorses of choice for the institute. ISE's owner, James R. McFarlane, staged an ROV demonstration for Packard and the MBARI management team. McFarlane's son was the pilot on that dive. After seeing the sub pick up a clam and bring it to the surface with its robotic arm, Packard commissioned ISE on the spot to build a submersible for MBARI and hired the younger McFarlane as the institute's first ROV pilot.

In October 1987 ISE began construction of *Ventana*, which was given the Spanish name for its destiny: "window" to the depths of Monterey Bay. After three months of construction and a month of sea trials, the core vehicle and tool-sled frame were shipped to Monterey. In short order *Ventana* acquired its first customized instruments: a three-chip, broadcast-quality video camera in a custom-built aluminum housing and a CTD unit for measuring salinity, temperature, and depth. Six lights, about as bright as an automobile's, were mounted on the core vehicle, as well as a "manipulator jaw" for grabbing samples.

On August 25, 1988, the freshly refurbished *R/V Point Lobos* brought the newly equipped *Ventana* out to sea for its first dive.

On August 25, 1988, the freshly refurbished *R/V Point Lobos* brought the newly equipped *Ventana* out to sea for its first dive. The operations team chose a site on the shallow reef off Hopkins Marine Station in Pacific Grove, and *Ventana* was lowered over the side and put through its paces. The ROV collected its first sample that day, a rock that years later was identified as a carbonate fragment, probably from a cold seep.

In little more than a year, MBARI had both an operational research ship and an ROV—an achievement of which Packard was justly proud. It was an auspicious beginning.

Over the past decade, the *R/V Point Lobos* has received constant upgrades and modifications to meet a brisk schedule of up to four cruises per week, primarily in Monterey Bay waters. *Ventana's* capabilities also have matured considerably over the years, with the acquisition of high-intensity lights, scanning sonar, flowmeters, oxygen sensors, a transmissometer, a structured light system, and assorted still and low-light cameras. A multi-beacon, ultra-short baseline system also has been added to relay the ROV's position relative to the ship. *Ventana's* first, all-purpose, detachable toolsled was a metal frame with a sample drawer. A caboose with high-flow suction for collecting animals was soon attached, then later augmented with another unit dubbed the "sled of death" for its capacity to pump formaldehyde into the sample canister, preserving specimens *in situ*. A seven-function, spatially correspondent manipulator was part of the core equipment; this arm was nick-named "Mongo" and soon endeared itself to researchers and ROV pilots for its dexterity.

In 1992 a drill sled with a single-barreled drill, developed by MBARI and collaborators from the international Ocean Drilling Project, made its debut. Using diamond-impregnated drill bits, the device excavated solid rock cores from Monterey Canyon walls. The occasion marked the first time an ROV was employed to collect geological cores. Two years later institute engineers and technicians refined a more powerful, multi-coring drill, allowing geologists to recover four one-meter-long cores per dive. MBARI staff have also designed a versatile midwater toolsled. Animals drawn into its suction tube are gently corralled into one of the dozen canisters that rotate into place under the intake, a system

Ventana with artifacts from the wreckage of the USS Macon, February 1991.

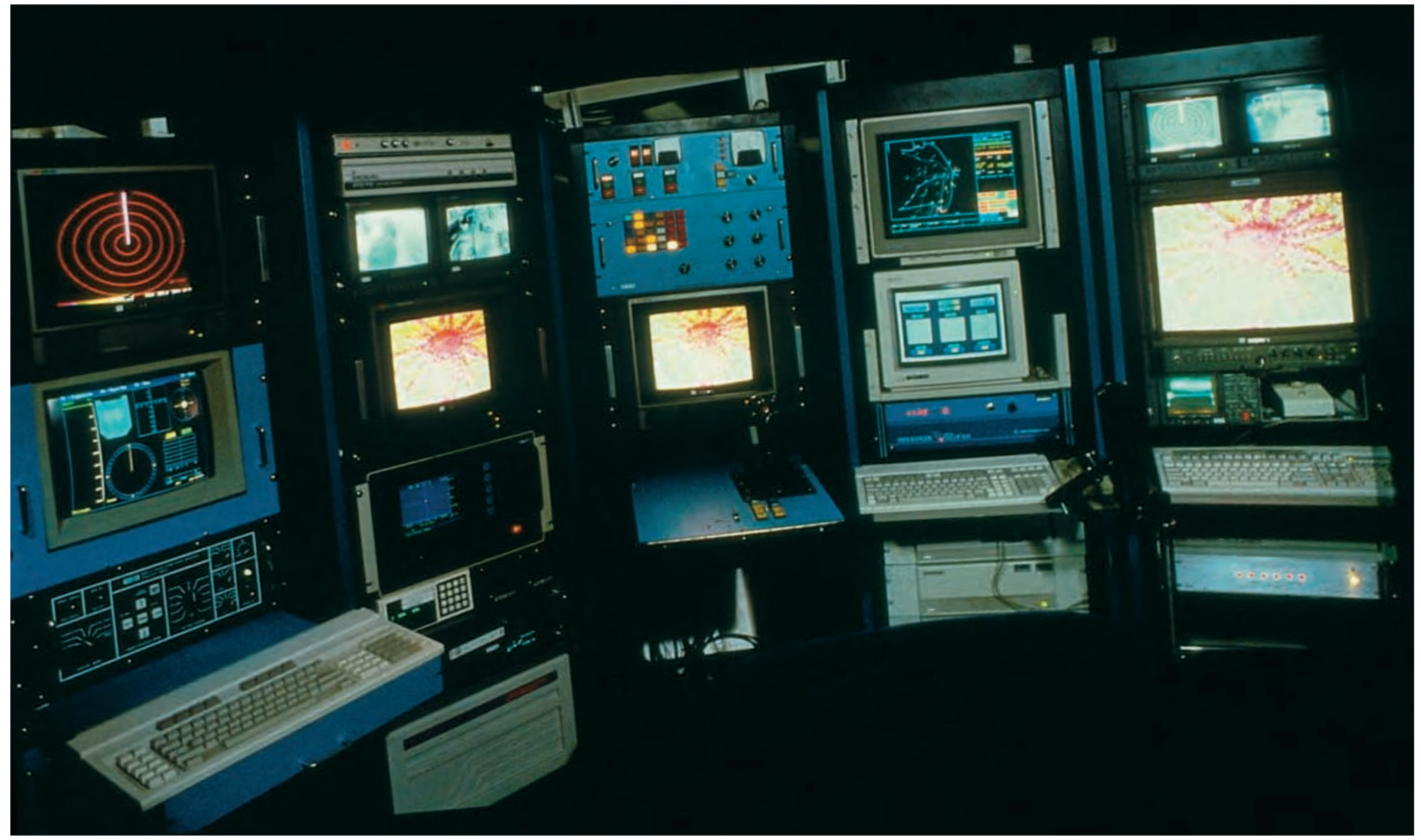
that has permitted the live capture of animals for laboratory studies.

A highlight in the joint history of the *R/V Point Lobos* and *Ventana* came in February 1991 when the duo was used to survey the remains of the *USS Macon*, an airship which crashed off Point Sur in 1935 with a cargo of four planes. A series of searches for remnants of the airship had proved futile. Then in 1989 a crucial clue emerged. An institute ROV pilot was given information about possible *Macon* debris, which a fisherman had dredged up and displayed in a local restaurant. Using information from the fisherman's navigation log, a Navy submersible finally located the *Macon's* debris field off Point Sur. With side-scan sonar and video and still cameras, an MBARI operations team investigated the site in detail and recovered artifacts. Ashore, David Packard watched the expedition closely via a short-range microwave relay station.

In 1992, not long after the *Macon* discovery and exploration, MBARI received an award for the innovative use of ROVs for science research from the Marine Technology Society. The winter issue of the society's journal that year, devoted to ROVs, included six papers authored by institute staff.

In late 1995 the *R/V Point Lobos* celebrated its thousandth science cruise, and *Ventana* made its thousandth dive, chalking up more successful missions than the combined total of all other similar ROVs used for science worldwide, according to a published survey. The same year, *Ventana* received a mid-life overhaul, gaining in overall dimensions and weight. The ROV got a new frame and a foam pack painted tangerine-orange and blue, in imitation of the blue-banded gobie, a fish native to Monterey Bay. An additional seven-function, spatially correspondent manipulator was added to complement "Mongo," and upgraded thruster components increased propulsion capacity. Finally, a new 2,100-meter-long (7,000-foot-long) electronics cable, the ROV's tether to the mother ship, increased its depth capability. In 1996 *Ventana* made its deepest dive yet, to 1,641 meters (more than 5,400 feet).

As of June 1997 the ship had completed more than 1,400 missions, and *Ventana* had performed more than 1,250 dives. MBARI's achievements have depended in no small part on



The science control room aboard the R/V Point Lobos contains monitors and control panels used to navigate Ventana and manipulate instruments while scientists and pilots view video images and displays of oceanographic data.

the expertise of its operations staff and the reliability of its first-generation ocean hardware. As a team, they have made ocean exploration by ROV almost routine. Day after day, scientific investigators and ROV operators have sat side-by-side in the *R/V Point Lobos* control room, manipulating cameras and instruments to plumb the deep, collect specimens, and record thousands of hours of video images. Together they have choreographed the *pas de deux* between the underwater science platform that can move like a dancer and the strong steady ship that supports it.

M. Leet for MBARI

Carole Sakamoto and Hans Jannasch in the laboratory with the OsmoAnalyzer they helped to develop.

What are the links between physical forces and biological populations in the oceans?

How are seawater chemistry, productivity, and the cycling of seasons related?

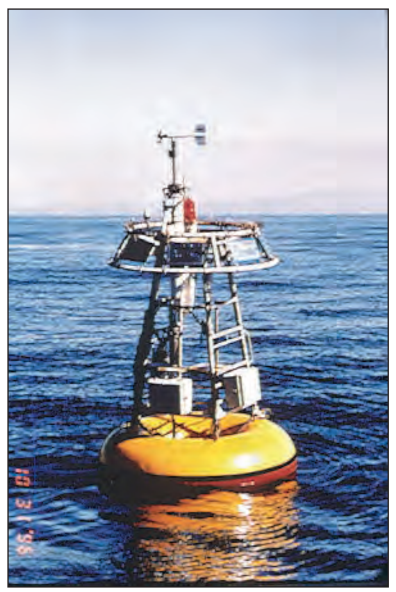
Seeing the Invisible: Biogeochemistry and Ecology in Ocean Waters

Perhaps no avenue of research at MBARI better exemplifies continuous, long-term research on broad questions than the studies on marine ecology and biogeochemical cycles. The quest to decipher relationships between climate, ocean circulation, seawater chemistry, the cycling of organic materials, and the abundance of organisms is a long-standing one in oceanography. Contemporary ecological concerns have cast urgency on the quest. The number of humans living within a few miles of the ocean is escalating, and apprehensions over the prospects of global climate change are on the rise. The need to assess human impact on the biosphere presses marine scientists to address such questions as:

What are the links between physical forces and biological populations in the ocean? How are seawater chemistry, primary productivity, and the cycling of seasons related? How do variations in water temperature affect the abundance and distribution of marine organisms? What role does the ocean play in regulating the planet's climate? How much of the carbon-containing material produced by photosynthesizing algae is recycled in the water column? How much sinks to the ocean floor? Which chemical compounds ultimately regulate phytoplankton production? How do winds, sea states, temperature, humidity, and primary production affect the transfer of carbon dioxide between the atmosphere and the ocean? Is the ocean a sink or a source for atmospheric carbon dioxide?

The challenge to understand the invisible links between biology, chemistry, and the physical ocean environment is magnified by the ocean's vastness, technological limitations to collecting information, and the wide variation in scales of time and space among the interacting factors. From MBARI's beginnings, that challenge has presented a prime opportunity for acting on the institute's mission to develop better instruments, systems, and scientific research methods.

The goal in Central California waters has been to compile an extensive, long-term record of ocean variability by means of frequently repeated measurements of seawater characteristics.



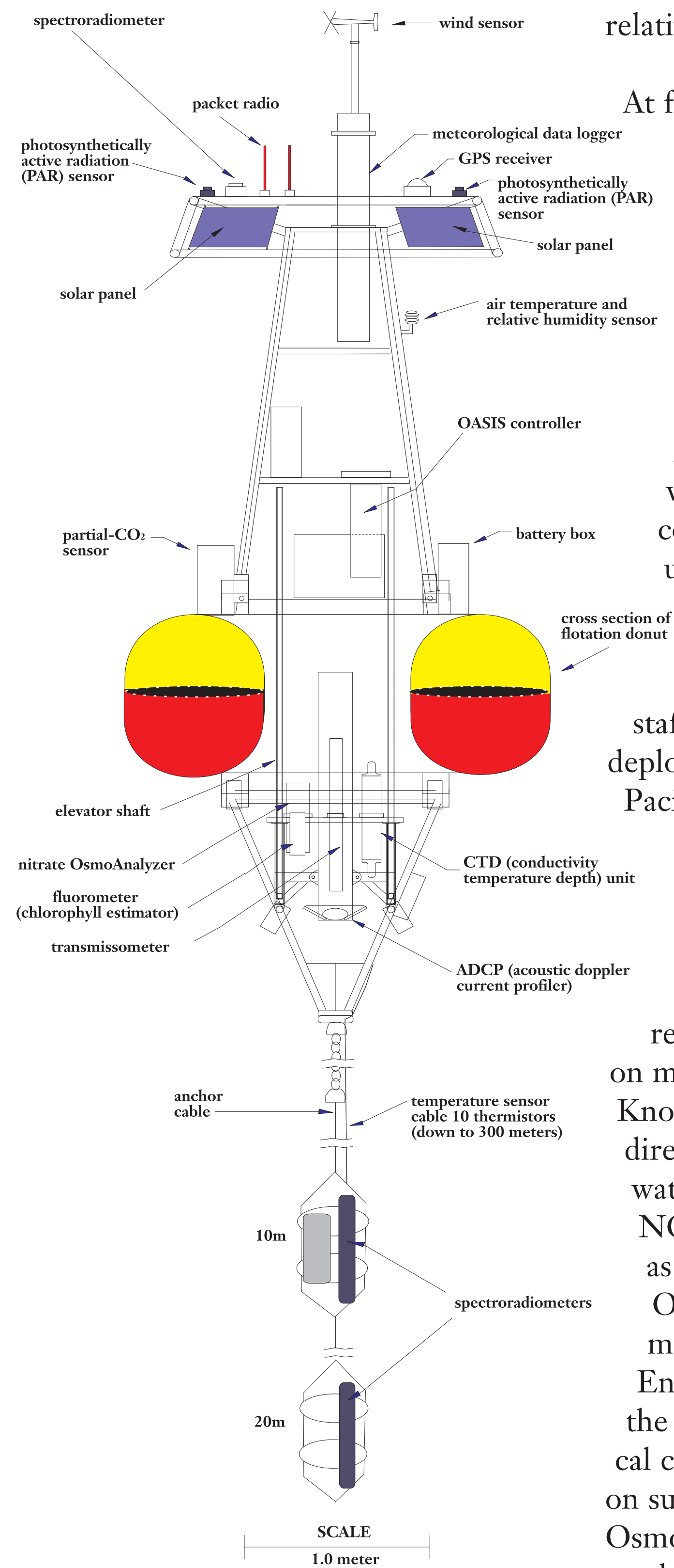
M1, the institute's mooring in Monterey Bay. In 1992 the MBARI-engineered OASIS controller, capable of collecting data from 20 instruments and automatically relaying them to shore, was installed on both MBARI moorings.

Over the last decade, institute scientists have conducted in-depth biogeochemical studies in the Monterey Bay area and have participated in numerous similar research efforts in the equatorial Pacific and other key locations around the world. The goal in Central California waters has been to compile an extensive and long-term record of ocean variability by means of frequently repeated measurements of a host of seawater characteristics. The starting points were traditional oceanographic methods: shipboard sampling and data collection from instruments on moorings.

In 1989 MBARI researchers initiated the Monterey Bay time series. Since then, every two to three weeks, on ship cruises along defined coastal tracks, they have measured temperature; currents; particulates; carbon-dioxide and chlorophyll levels; nutrients such as nitrate, silicate, and iron; and more than a dozen other water properties. These measurements reveal physical, biological, and chemical patterns in the bay and, further offshore, in the California Current.

Institute scientists in 1992 made a technological advance toward automating seawater chemistry measurements in real-time on ship cruises. Modifying conventional lab equipment, they developed a sampling system that allows for continuous monitoring of nitrate, a crucially important nutrient for algae that varies greatly in availability. Chemical analyzers for ocean sampling in use at the time employed peristaltic pumps, which required constant maintenance. MBARI researchers substituted syringe pumps, which need only minimal operator intervention, for drawing water and mixing reagents with the samples. They also wrote computer software that adds geographic information to the nitrate data, making it possible to compile seawater chemistry maps.

As valuable as the shipboard time series proved to be, MBARI researchers knew that more frequent sampling is necessary for discerning events and processes in the ocean. Dynamic changes there can happen in a matter of hours, as with increases in phytoplankton populations, or over decades, as with climate shifts. To progress from periodic sampling of organisms and water properties to more continuous monitoring, the institute, with assistance from NOAA/PMEL[1], deployed a pair of offshore mooring systems in 1989. The moorings were positioned in two areas of contrasting oceanographic characteristics. M1 was placed



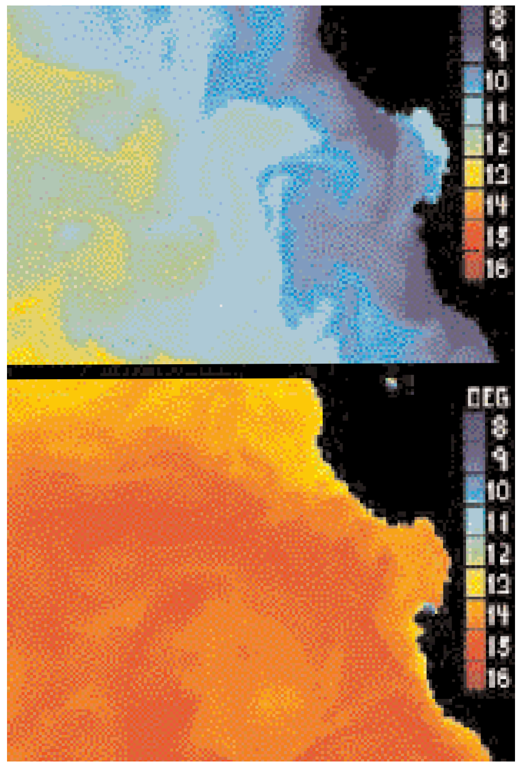
Configuration of instruments on M1 and M2 moorings.

inside Monterey Bay proper, where spring and summer generally bring on the upwelling of cold, salty, nutrient-rich water. M2 was anchored outside the bay in the relatively warm water of the California Current.

At first the moorings were equipped only with instruments to measure temperature and wind. Over the years M1 and M2 have acquired a suite of additional sensors and samplers, several of which are the brain-children of MBARI staff. One is an apparatus to measure the difference between the partial pressure of carbon dioxide in air and that of the sea's surface. Another innovation is a general-purpose electronic controller dubbed OASIS (Ocean Acquisition System for Interdisciplinary Science), which was installed on the moorings in 1992. Able to collect data from up to twenty instruments and continuously relay the information to shore by packet radio or satellite, OASIS represents a quantum leap to real-time ocean sampling—made possible by the joint efforts of scientists, engineers, and operations staff at the institute. In 1996 MBARI technicians deployed two OASIS-equipped moorings in the equatorial Pacific as part of NOAA's Tropical Atmosphere and Ocean array.

In 1994 the program, which acquired the acronym MOOS (for MBARI Ocean Observing Systems), received yet another technological boost with the refinement of a chemical sensor that can be mounted on moorings and left unattended for several months. Known as the OsmoAnalyzer, it uses an osmotic pump to directly measure levels of nitrate, a key nutrient in ocean waters. Nitrate OsmoAnalyzers have been installed on NOAA moorings and on buoys off Hawaii and Bermuda, as well as on the MOOS moorings. As of 1997, OsmoAnalyzers for silicate, sulfide, iron, and manganese were all under development at the institute. Engineers are also designing a solid-state analyzer with the potential to simultaneously measure multiple chemical compounds and a digital analyzer that can be deployed on submersibles. Another MBARI-developed device, the OsmoSampler, has been placed at sites in Monterey Bay, on the Juan de Fuca Ridge off the Oregon coast, and on the Hawaiian submarine volcano Loihi. The OsmoSampler can be left on the seafloor for up to four years, periodically pumping fluids from sediments into a very small-bore tube, which can then be recovered for analysis of a large number of discrete samples.

These *in situ* devices, capable of continuous recording of trace metals, nutrients, and other critical compounds cycling through the oceans, represent an important step beyond traditional sampling methods. They are but the first in MBARI's long-range program to transfer many resource-intensive shipboard measurements to moorings and other autonomous platforms by developing new instruments and systems. Such leading-edge technology can serve as building blocks for autonomous time series around the world, helping to fulfill the ocean-monitoring goals of international programs such as GLOBEC[2] and JGOFS[3]. It will allow researchers to discern in much greater detail seasonal and inter-annual climate patterns, upwelling events, marine geological processes, plumes of particulate material from rivers and land, and other environmentally significant changes in ocean chemistry.



Satellite data are used to generate seasonal maps of sea-surface temperatures. Upwelling of cold (blue) water is normally a spring-summer event in Central California coastal waters (top image).

Warmer water temperatures (orange-red) are typical of fall-winter (bottom image).

In 1994 the institute added a satellite receiving system. It collects remotely sensed images of sea surface temperatures that provide insights into the circulation patterns of the complex Monterey Bay area. Data on ocean color—which became available from the SeaWiFS[4] satellite launched in mid-1997 and for which MBARI is a primary downlink site—will reveal patches of high chlorophyll concentrations, making it possible to detect phytoplankton blooms.

The link between phytoplankton growth and the availability of iron in ocean waters was clarified by the 1993 and 1995 "Iron-Ex" experiments, in which MBARI researchers participated. Aided by navigational technology developed at the institute, the 1995 research team traced the effects of enriching a big patch of ocean west of the Galapagos Islands with a large quantity of iron. The results—a dramatic but temporary increase in phytoplankton populations—showed clearly that iron limits productivity in the equatorial Pacific, highlighting an aspect of ocean variability previously unrecognized.

As of 1997 the Monterey Bay shipboard time series had evolved into the most intensive effort in the nation to date

From baseline data on the bay, researchers can now identify disturbances, such as El Niño events, and evaluate their mechanisms and effects.

for monitoring the coastal ocean environment. And, after eight years of data collection, the MOOS moorings support some of the most sophisticated ocean monitoring instruments found worldwide. The mooring arrays include more than a dozen sensors for gauging air and sea temperatures, salinity, density, currents, precise geographic location, solar radiation, chlorophyll concentrations, bio-optical properties, and other measurements. Together the moorings, regular shipboard surveys, and satellites give MBARI researchers information for tracking the abundance and distribution of organisms at a level of detail not previously possible. This in turn provides insights to the complexities of primary production, marine food chains, and the decomposition that returns nutrients to the web of life.

Plugging the collected data into conceptual models of the Central California coastal and offshore ecosystem sometimes produces surprising results. For example, in studies to determine the fate of organic material produced by phytoplankton, referred to as "new production," early findings indicate that substantially less material than expected is sinking to the seafloor off Central California. MBARI models suggest that much of this new production is transported horizontally by strong offshore winds. This discovery has underscored the need to add more moorings to MOOS in the near future and to expand observations further outside the bay.

Through the efforts over the last decade, MBARI researchers have been able to describe the mean conditions and seasonal variability of Monterey Bay's atmospheric, biological, physical, and chemical processes. A more in-depth understanding has emerged about seasonal patterns in the bay and the links between climate, ocean physics, and phytoplankton growth rates. The baseline data on the bay is now adequate for researchers to identify disturbances, such as El Niño events, and to evaluate their mechanisms and effects. It is now also possible to better discern the effects of human activities and assess their significance with respect to global climate change.

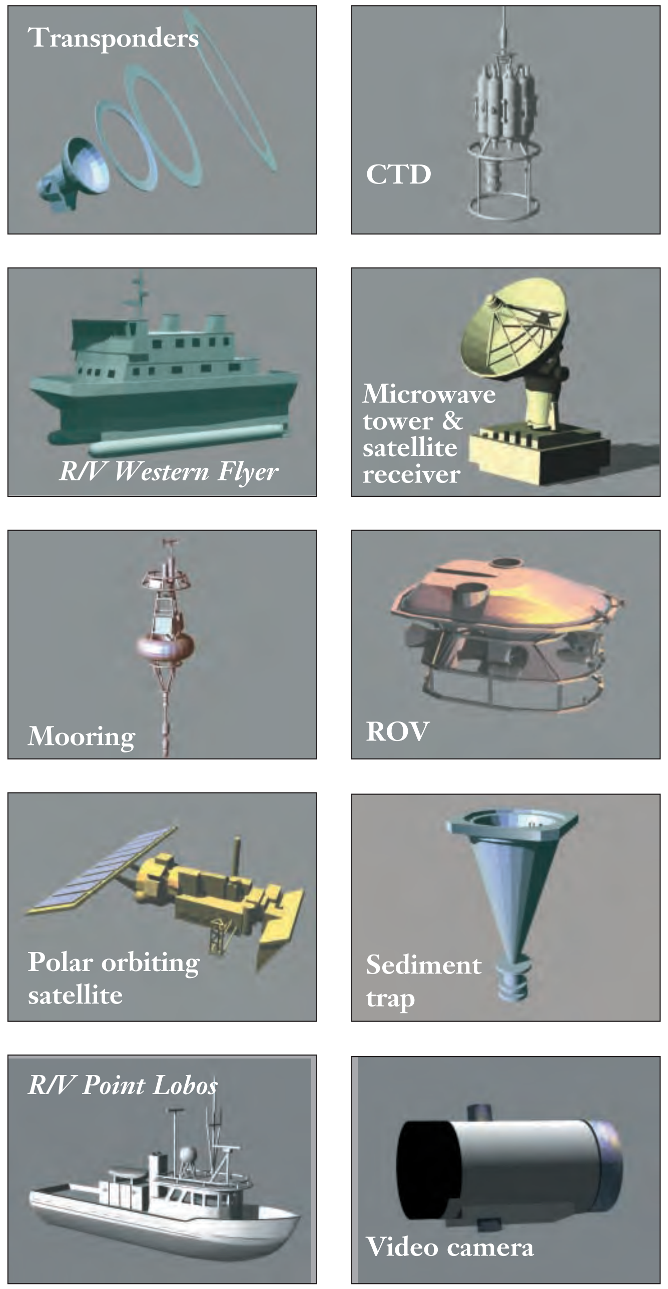
While no marine area can encompass all the variety of the world's oceans, Monterey Bay and the adjacent waters, which span from areas of rich coastal upwelling to oligotrophic open ocean, provide a laboratory for studies broadly relevant to much of the planet's water-covered realm. The improved methods and instruments developed for penetrating the complexities of Monterey Bay and the insights gained by long-term observations there, has given MBARI a good deal to share with the scientific community.

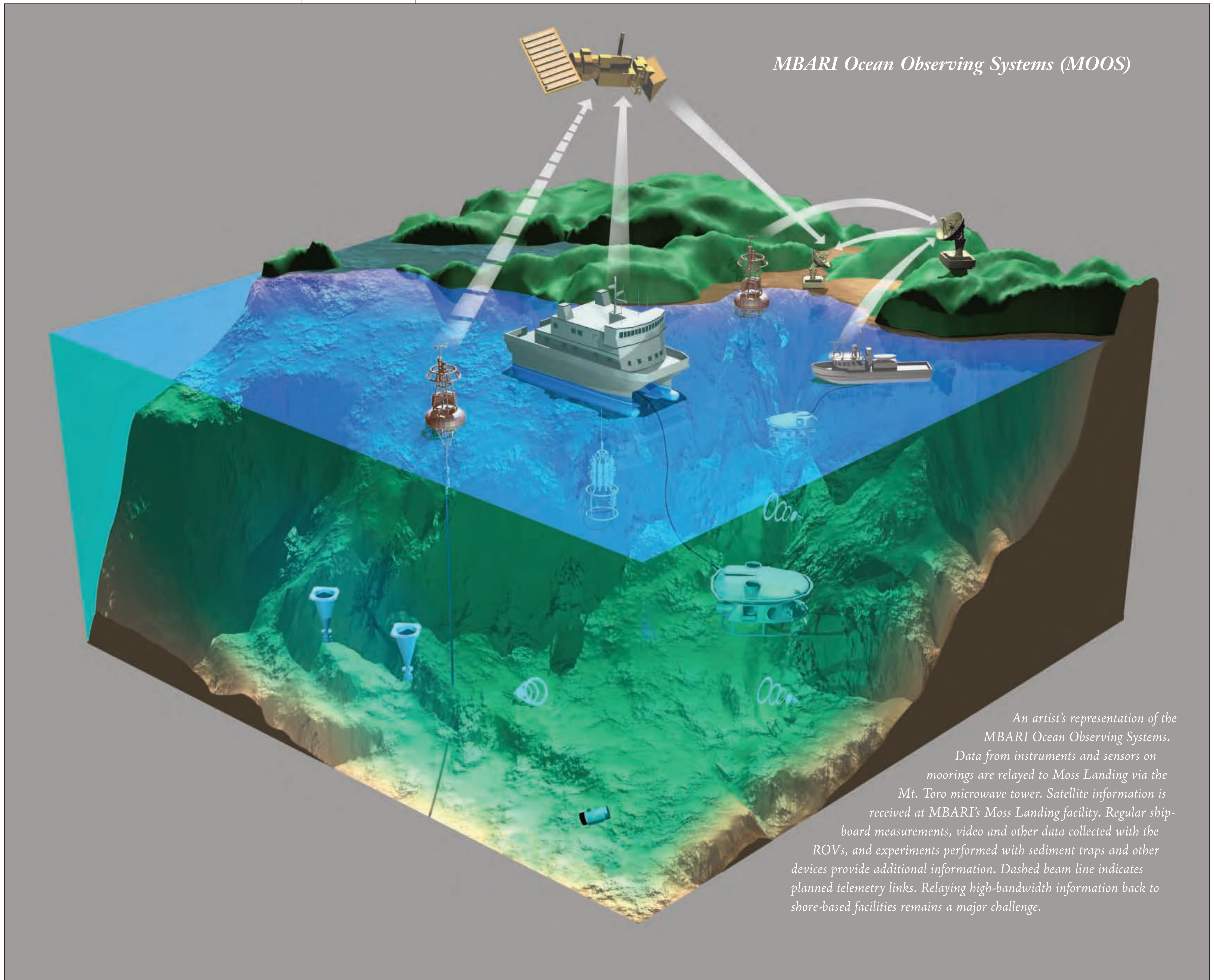
[1] *National Oceanic and Atmospheric Administration/Pacific Marine Environmental Laboratory*

[2] *Global Ocean Ecosystems Dynamics*

[3] *Joint Global Ocean Flux Study*

[4] *Sea-viewing Wide Field-of-view Sensor*





An artist's representation of the MBARI Ocean Observing Systems. Data from instruments and sensors on moorings are relayed to Moss Landing via the Mt. Toro microwave tower. Satellite information is received at MBARI's Moss Landing facility. Regular ship-board measurements, video and other data collected with the ROVs, and experiments performed with sediment traps and other devices provide additional information. Dashed beam line indicates planned telemetry links. Relaying high-bandwidth information back to shore-based facilities remains a major challenge.

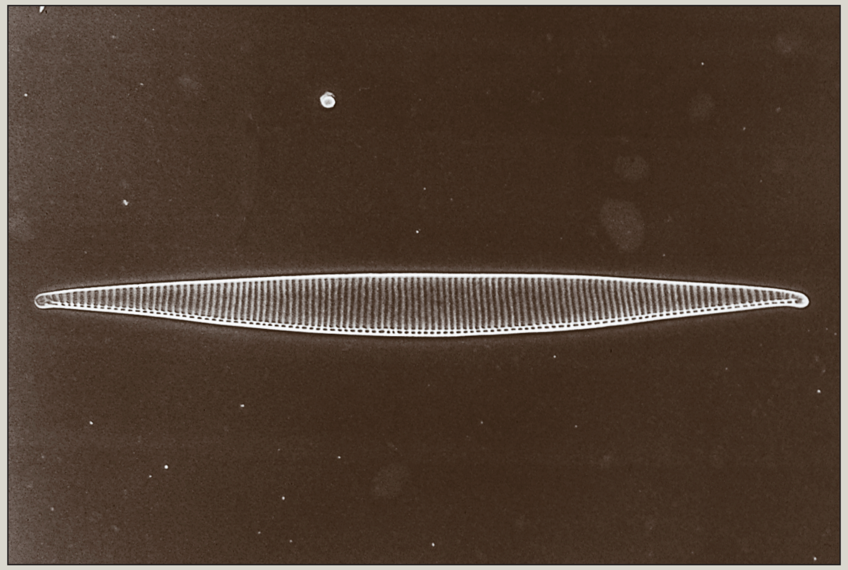
HARMFUL ALGAL BLOOMS

Hundreds of harmful algal blooms occur each year, often sickening and killing humans and marine animals.

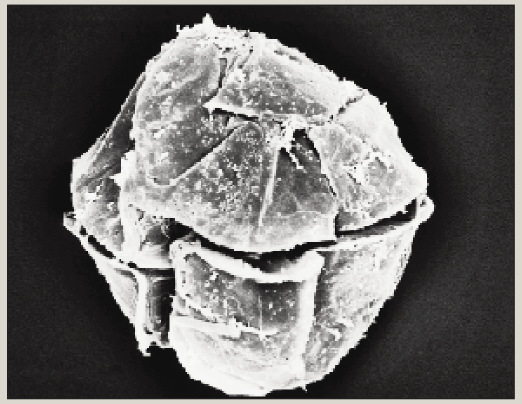
In September 1991 more than 200 dead cormorants and pelicans washed up on Monterey Bay shores. Some scientists initially thought a bacterial infection had killed the birds. On a cruise for the Monterey Bay time series, MBARI scientists found elevated algal counts, which indicated a bloom in progress. After weeks of additional sampling and analysis, in collaboration with other researchers, they determined the cause of the bird deaths was poisoning by domoic acid, a toxin produced by certain species of the diatom *Pseudo-nitzschia.* The birds had apparently fed on fish that had ingested the microscopic algae and, after suffering damage to their nervous systems, had perished. During the following months, many tons of local anchovy catches had to be diverted or recalled.

The incident was the result of one of the hundreds of harmful algal blooms that occur each year around the world, often sickening and killing humans and marine animals, as well as incurring millions of dollars in economic losses due to damaged fisheries and lost tourist revenues. Many scientists believe that the frequency and intensity of harmful algal blooms are on the rise throughout coastal areas of the world.

Chris Scholin, molecular biologist, at work in his MBARI lab, refining probes for detecting toxic algae.



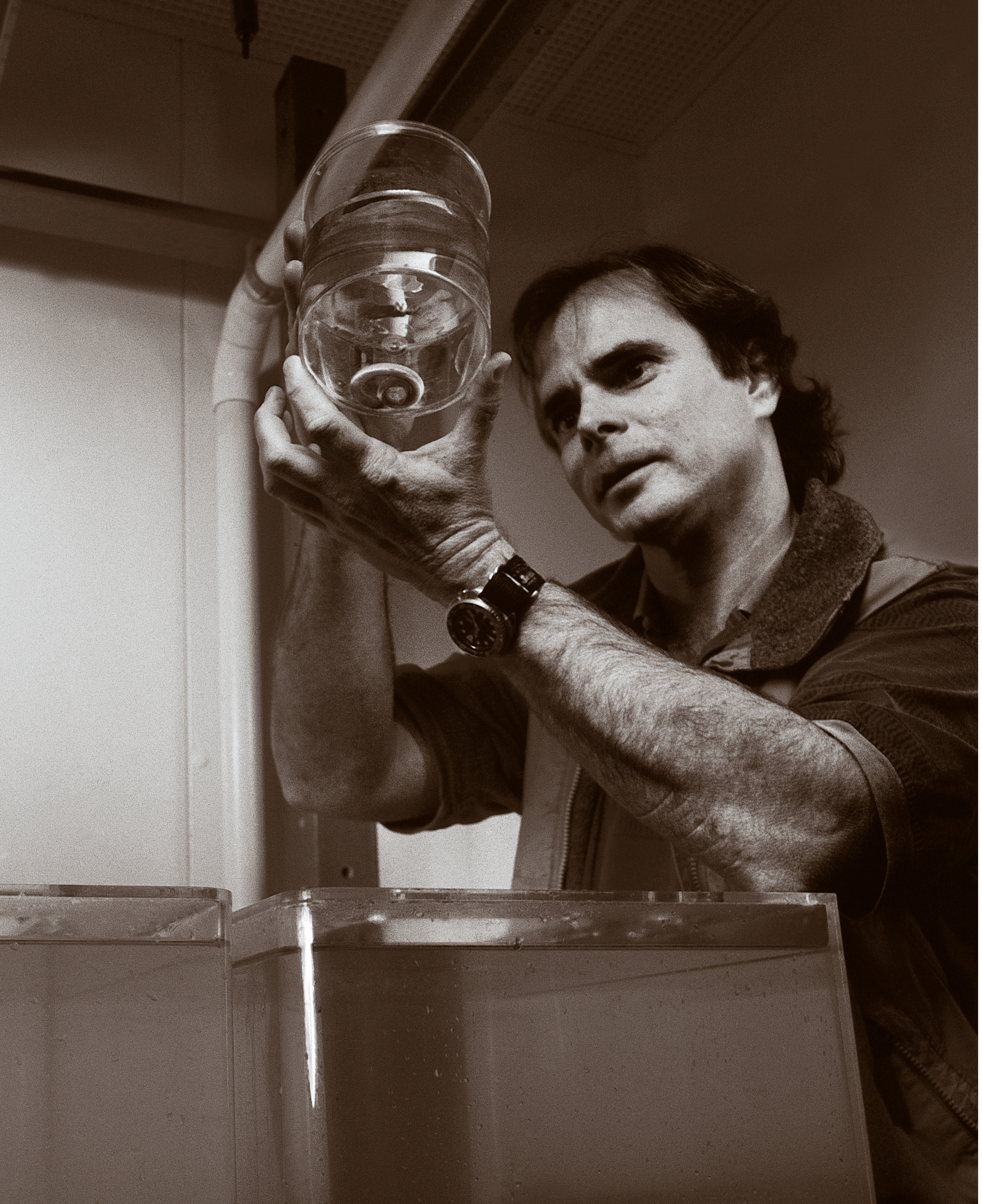
The scanning electron micrograph shows details of the diatom Pseudo-nitzschia australis *(about 85 microns in length).*



The scanning electron micrograph shows the dinoflagellate Alexandrium tamarense *(35 microns in diameter).*

The 1991 episode underscored the basic difficulty in responding effectively to harmful blooms. The conventional method of identifying toxic algae in water samples is painstaking, labor-intensive microscopic analysis. There is a considerable lag time between sample collection and the identification and counting of the culprits to determine if their numbers pose a health threat. This severely limits the ability to predict when and where potentially poisonous organisms may show up and endanger public health or wildlife.

A postdoctoral researcher with a desire to develop methods for the swift identification of toxic algae—and uncanny timing—arrived at the institute in 1991 and set to work on the challenge. Borrowing techniques from biotechnology, he and his team have designed two methods that use genetic probes for assaying harmful strains of *Pseudo-nitzschia* and *Alexandrium*, another toxic microorganism found worldwide. As of 1997, public health and wildlife agencies were employing the probes in coastal areas around the U.S., and in 1996 and 1997 researchers used them in New Zealand to successfully predict the outbreak of algal-borne toxins in commercially grown shellfish. Refinements of these diagnostic tools that can be used outside conventional lab settings are currently underway at MBARI. These advances and the development of additional probes for other harmful organisms hold significant promise for improving global public health responses to harmful algal blooms.



M. Leet for MBARI

How much life is really down there? What do the denizens of the deep look like, and how do they behave?

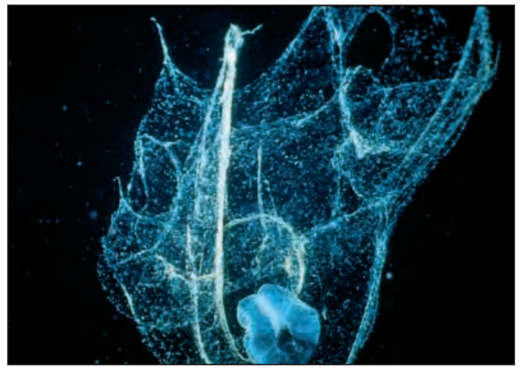
Kim Reisenbichler examining specimens in MBARI's chilled-seawater biology laboratory.

Exploring Earth's Largest Living Space–Ocean Midwaters

Between the surface of the sea and the ocean floor lies a vast fluid universe, Earth's least-known environment. Ocean scientists have strived for almost two centuries to comprehend the unseen depths, seeking answers to questions such as: How much life is really down there? What do the denizens of the deep look like, and how do they behave? What are their strategies for survival in an environment so unlike our terrestrial one? How does the physical environment vary from illuminated waters to the dark depths, and how do these variations shape animal communities? It has taken a technological revolution to finally make systematic deep-sea exploration feasible, to thrust ocean science beyond the traditional net tows and shipboard sampling that could barely hint at the world beneath the surface of Earth's watery portion.

The promise of discovery offered by the 1985 submersible dives in Monterey Bay was a driving force in the founding of MBARI and a powerful incentive to push remotely controlled vehicles to unprecedented levels of performance. The high operational reliability of the institute's first ROV, *Ventana*, with its sophisticated cameras and sensors, has afforded investigators the opportunity to spend thousands of hours surveying and describing the deep waters of the bay. The institute's program of observation of little-known life-forms in their native habitat and collection of once-rare specimens for laboratory studies is the most extensive such effort to date.

The steepness of Monterey Canyon is perhaps its greatest advantage for research. Only 32 kilometers (20 miles) from shore, MBARI's ships are afloat in 2,000-meter (6,600-foot) depths. Sixty-five kilometers (40 miles) out, the depth exceeds 3,000 meters (9,800 feet), and another several kilometers outside the canyon the seafloor drops off to the abyssal plain some 4,000 meters (13,100 feet) below the sea's surface. The presence of deep water so close to shore



(top) Giant larvacean, Bathochordaeus *sp.*

(bottom) Deep-water siphonophore of Monterey Bay, Halistemma, *with a fish caught in its dangling tentacles.*

not only makes regular forays with *Ventana* convenient; it also allows researchers to use the canyon as a window on communities of the open ocean. The reward of regular investigations of midwater ecology with an ROV is a radically new perspective on the deep sea. This perspective is making it possible for scientists to assemble an increasingly detailed picture of animal communities in the twilight zone of the ocean.

Perhaps the biggest surprise to date is that the types and numbers of animals in deep waters are fundamentally different than conventional sampling methods had indicated. In the past, net hauls had brought to the surface animals such as shrimps, lanternfishes, and squids—often accompanied by considerable quantities of unidentifiable gooey material. From the start, MBARI researchers were seeing a much greater variety of life through *Ventana's* cameras. The jellied matter once found in nets was now visible as blizzards of decomposing particles, called marine snow, and fragile but intact gelatinous animals. Their diversity was unexpected, and the jellies seemed to be everywhere. In 1990 *Ventana* captured rare images of deep-sea medusae near the seafloor in densities of up to 80 individuals per cubic meter. Jellies are so pervasive in the bay that researchers suspect they comprise up to one-quarter of the biomass there. Among other discoveries, MBARI researchers have found at least 10 undescribed species of ctenophores, or comb jellies.

An important group of widespread and abundant gelatinous animals studied closely by midwater specialists at MBARI is the larvaceans. Possessing tadpole-like bodies, larvaceans are filter-feeders. They secrete mucous to form balloonlike filters, a few centimeters to a few meters in diameter, for straining large particles out of the stream of smaller ones they feed on. The first-ever extensive observations of a deep-sea larvacean in its natural environment occurred on a *Ventana* dive in 1988, when a pilot used the ROV to track one for more than an hour, to the delight of the scientists and pilots aboard the *R/V Point Lobos*. Since then institute researchers have begun to elucidate the feeding strategies, diets, and other behavior patterns of particle-processors such as *Bathochordaeus*, whose mucous "house" measures up to two meters wide. They have learned that four larvacean species thrive at different depths in the upper kilometer of Monterey

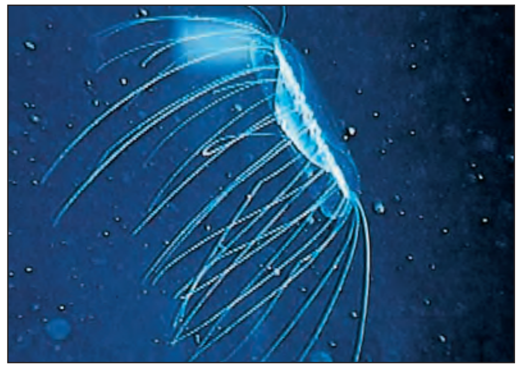
How does the physical environment vary from illuminated waters to the dark depths, and how do these variations shape animal communities?

Bay waters, each feeding on certain sizes and densities of particles. Three of these species are new to science.

Larvaceans routinely abandon their houses after they become clogged with particles. Institute researchers have found that the voluminous houses of giant larvaceans sink relatively rapidly and transport considerable material from upper waters to the seafloor. Smaller larvacean filters, along with molts, fecal pellets, and bits of cast-off animal parts, contribute to a continuous flurry of marine snow, which has also been the focus of much study at MBARI. In their gradual descent from the upper ocean to the seafloor, marine-snow particles sustain populations of bacteria and tiny animal grazers, living out cycles of life, death, and decomposition. Oasis communities residing on marine snow and other free-living organisms have come to be recognized as the "microbial loop," a branch of marine food-webs that includes the smallest living particles in the oceans. In 1989 institute researchers and collaborators discovered a previously unknown member of the latter group: *Acanthocorbis haurakiana*, a protozoan that ingests bacteria.

To begin to get a handle on just how much marine snow exists, institute engineers designed a special array of lights and mounted it in front of *Ventana's* video camera in 1990. Knowing the defined volume of light that illuminates the falling snow, researchers can derive image sizes from the video recording. Then, from the calibrated images, they can estimate the amount of suspended material. Such estimates are helping to determine how much of this ocean detritus occurs at different depths and how much of the carbon-rich material reaches the ocean floor to feed seafloor animals or get buried in sediments. The rain of refuse may play a prominent role in the draw-down of carbon-dioxide from the atmosphere to the ocean, an effect scientists have been trying to measure ever since global warming became a concern.

Biologists studying groups of animals look for organizing principles they refer to as community structure. Vast and dimensionless as the ocean seems, over the last decade MBARI scientists have begun to understand the outlines of community structure there. Their ability to gauge the density and distribution of animals, an important aspect of community structure, was boosted in 1993, when *Ventana* acquired a combination flowmeter-odometer. This device



Midwater narcomedusa, Solmissus marshalli, *surrounded by marine snow.*

measures the distance covered and the corresponding volume of water passed through as the ROV makes systematic horizontal transects at defined depths. Using it, researchers can match reasonably accurate measurements of animal numbers with conditions such as depth, temperature, light, and oxygen levels—all variables that help define deep-sea habitats. The time-series data derived from these efforts comprise the first such database ever assembled for a deep midwater community.

Ventana's surrogate eyes have looked into the secret lives of octopuses and squids also, proving the ROV a superior tool for gaining access to their all-but-inaccessible worlds. An in-depth study of squids at MBARI in the mid-1990s shed light on the behavior of more than a half-dozen species. New information was collected on squid ecology, distribution, developmental patterns, migration habits, body language, bioluminescent responses, movements, and other details.

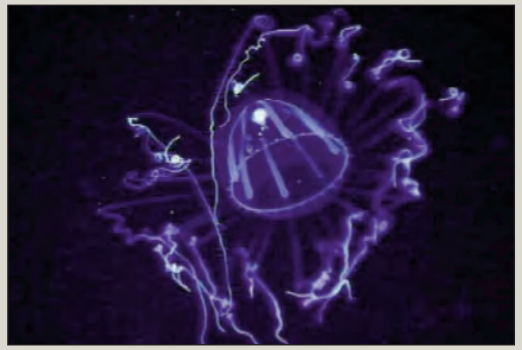
Siphonophores—some of which measure 40 meters (130 feet) in length, longer than a blue whale—are another wide-ranging group of gelatinous animals that has provided insights into deep-water communities, particularly in terms of who eats whom. It turns out that siphonophores are major predators in the midwaters. One species alone, *Nanomia bijuga*, accounts for about one-quarter of the predation on krill, an important source of food in the bay. Some specimens collected in the bay are chemically preserved immediately upon capture. This increases the reliability of lab analysis of their stomach contents back at the institute and allows researchers to evaluate their impact as predators. Other specimens are returned alive to MBARI's chilled-seawater lab for long-term studies of feeding, digestion, behavior, reproduction, and respiration. Whether siphonophores are organized colonies of individuals or a single super-organism remains a paradox. However, MBARI midwater specialists, who have discovered a dozen previously unknown siphonophore species, have found them to be more complex in behavior and physiology than was previously thought and undeniably important to ocean ecology.

Other surprising findings have come from investigations of the layer of depleted oxygen that occurs between 650 and 850 meters (2,150 to 2,800 feet) deep in Monterey Bay.

Jay Hunt observes a vampire squid (Vampyroteuthis), *collected by midwater researchers, in a kreisel tank in MBARI's chilled-seawater laboratory.*

Despite the fact that the oxygen content of the water in this zone plummets to less than one percent of that at the surface, animals such as the archaic cephalopod *Vampyroteuthis* have adapted to live there. Institute scientists suspect that one key to understanding the chemical nature of the oxygen minimum layer lies in the milky layer of particles at the bottom of this zone.

Many of MBARI's most stunning discoveries have come from the hundreds of hours of midwater ROV surveys. On the threshold of its second decade, with powerful new instruments and hardware in their early stages of use, the institute looks forward to going deeper, staying longer, and seeing more than ever in the ocean's deep interior.



(top) Deep-sea squid, Galiteuthis phyllura, *the cockatoo squid.*

(bottom) Midwater jelly, Colobonema sericeum, *drops its bioluminescent tentacles when disturbed.*

DEEP-SEA BIOLUMINESCENCE

Ventana's regular voyages to the depths provide constant reminders that the great majority—perhaps 90 percent—of animals that inhabit the upper two kilometers (about 6,600 feet) or so of ocean waters are capable of producing light, and much of the detritus suspended in the water glows when it is disturbed. Researchers pinned down the chemical mechanism of bioluminescence more than a century ago, but the purposes of such light displays have been much more elusive. Over the past decade MBARI midwater scientists have observed a range of animals wielding light: fragile shimmering comb jellies, medusae casting off glowing tentacles, lanternfishes shining bioluminescent photophores, fang-toothed fish dangling lures that harbor light-making bacteria, and many others. Institute research has uncovered previously unknown means by which ocean animals perform this magic, as well as some clues as to why they do it.

In 1991 an MBARI scientist published the first scientific paper to describe, from *in situ* submersible observations, how a deep-sea animal produces and uses its light. *Enypniastes eximia,* a swimming sea cucumber found in the Pacific, Atlantic, and Indian oceans from about 500 to 5,000 meters deep, lights up on physical contact. The light, generated by granular bodies in its gelatinous outer layer, spreads across the animal's entire body. An attack by a predator triggers the sea cucumber to shed its sticky, glowing skin—an anti-predatory behavior scientists refer to as a "burglar alarm," for its effect in revealing the would-be attacker to its own predators.

Close observations of the midwater squids *Chiroteuthis* (the swordfish squid) and *Galiteuthis* (the cockatoo squid) have shown that they use bioluminescence as camouflage. Both squids' bodies are transparent, except for their eyes and ink glands. Photophores located below their eyes shine downward, regardless of the position of the rest of the body, and eliminate their silhouettes. By producing a hue that matches the ambient light when viewed from below, the stealthy squids are virtually invisible to both predators and prey.

Deep in the oxygen-minimum zone, MBARI researchers have discovered another manifestation of bioluminescence in a primitive relative of the octopus and the squid, *Vampyroteuthis.* Little was known of this elusive animal before it was filmed by *Ventana's* cameras and live specimens were captured for studies at the institute's chilled-seawater lab. *Vampyroteuthis* has a football-shaped body, opal-blue eyes, a pair of sensory tendrils, and eight webbed limbs armed with suckers and fingerlike protrusions. Institute scientists have discovered that the tip of each limb is equipped with a light-producing organ. When this living fossil pulls its light-tipped arms up and over its mantle, it presents a glowing crown that may confuse predators. It can also eject bioluminescent mucus, instead of ink.

How do deep-sea animals produce light? Why do they do it?

Midwater specialists have witnessed another kind of bioluminescent display in a recently discovered tomopterid worm about 10 centimeters (four inches) long. This agile swimmer spews bioluminescent fluid from pores on its legs, creating a luminous cloud that engulfs the worm and trails behind it. Unlike the bluish hue created by other deep-sea flashers, the worm's light, the product of tiny glowing rods, is yellow—a mystery in a realm where most animal eyes are thought to respond only to blue-green light.

One of the most remarkable sights midwater scientists have encountered is a propagated display of bioluminescence, in which the natural movements of animals stimulate a large-scale chain reaction of flashing reminiscent of distant lightning. Just as MBARI's extensive underwater surveys have demonstrated rich diversity in what was once thought to be a mostly lifeless realm, observations in the deep sea have also revealed surprisingly frequent illumination in a zone once thought to be devoid of light.

Vampyroteuthis

M. Leet for MBARI

Debra Stakes holds a carbonate sample formed by bacterial action on the floor of Monterey Canyon. The data logger in the foreground can record earthquake activity that affects benthic communities and carbonate formation.

What species thrive in the micro-habitats of the seafloor? Which are rare, which abundant?

Peering into the Benthic Cosmos and the Canyon's Past

Like the land above sea level, the ocean floor represents a mosaic of environments. Benthic ecosystems cover virtually limitless combinations of physical, chemical, and biological conditions. Depth, temperature, availability of light and nutrients, and characteristics of the bedrock and sediments—all factors that influence seafloor communities—are in turn related to and affected by currents, tides, storms, and other events in the water above. Geological processes at and below the seafloor impact bottom-dwelling animals as well. The remarkably complex ocean bottom represents a realm as mysterious and alien as the cosmos beyond Earth's atmosphere. And, arguably, it is even more difficult to probe.

From MBARI's inception researchers have been documenting the details of life on and in the benthos, from about 100 meters (330 feet) deep on the continental shelf to depths of more than one kilometer (3,300 feet). They are addressing long-standing, long-range questions such as: What species thrive in the micro-habitats of the seafloor? Which are rare, which abundant? What strategies do benthic animals use for breeding and for perpetuating their species? How rapidly do denizens of the seafloor grow, and how stable are their populations? What physical and biological factors influence their survival? What life-forms exist in seafloor sediments, and what roles do they play in the benthic realm? How are biological, chemical, and physical systems of pelagic waters and the seafloor linked?

As with midwater investigations, the ROV *Ventana*'s surrogate eyes are a valuable asset for MBARI benthic scientists. *Ventana* made its first general seafloor survey in August 1988. Since then researchers have used such inspections to assess population patterns of sea stars, crabs, sea cucumbers, tunicates, clams, and other ocean-bottom residents. These surveys also have revealed behavioral patterns and promising locations for more in-depth research. Video images demonstrate that availability of food and underwater topography are key

(top) The predatory tunicate Megalodicopia hians, *was first described from specimens collected in Monterey Bay.*

(bottom) Brachiopods Terebratalia *sp.*

determinants of where benthic animals thrive. Basket stars and deep-sea urchins, for instance, depend on currents to deliver zooplankton and bits of kelp for nourishment. Institute scientists have observed these animals congregating at the bases of cliffs where food resources accumulate, thereby bettering their chances of catching a meal.

One group of benthic studies has focused on recruitment, the addition of new members into a population by immigration or reproduction. The larvae of brachiopods and other animals go through a planktonic stage before settling on a solid surface. To obtain estimates of the numbers of larvae that succeed in establishing themselves on the seafloor, institute researchers have left trays of material suitable for larval settlement at several sites. They have recovered trays from various depths, both near and far from adult populations, and counted the numbers of larvae that colonized the surrogate homes. The studies suggest that larval supply on the continental shelf is sufficient to sustain adult populations in areas with suitable physical characteristics. In general, however, larval abundance decreases with depth.

In 1994 institute ecologists laid out about a dozen permanent transects on the ocean bottom from depths of 150 to 1,000 meters (about 500 to 3,300 feet). They regularly survey these 100-meter-long (330-foot-long) transects, using video images to track the diversity and abundance of animals. By comparing the accumulated information from year to year and site to site, they gain a better understanding of rates of population change for some common benthic invertebrates.

Comparable methods were used in a collaborative study by marine ecologists from MBARI and the Hopkins Marine Station of Stanford University at a site in the shallowest part of the seafloor, the intertidal zone. In 1995 the researchers conducted an inch-by-inch survey of the types and numbers of animals living along a transect running between the high and low tide lines of Monterey Bay. Scientists from Hopkins had surveyed the same area in 1931-1933, so comparing the 1995 data with the first survey information allowed a detailed snapshot of changes in the intertidal community over six decades. The results were significant. Among the 45 species of invertebrates counted and compared between the two surveys, populations of

What strategies do benthic animals use for breeding and for perpetuating their species? How rapidly do they grow, and how stable are their populations?

eight of the nine species associated with warmer, southern coastal waters had increased. At the same time, the numbers of five of the eight species normally more prevalent in colder, northern coastal waters had declined. Adding to these findings, the records for annual mean shoreline temperatures between the 1930s and 1990s showed measurable increases, strongly suggesting that a sustained shift in climate was the best explanation for the findings. The study was the first to demonstrate the effects of more than a half-century of climate change in a coastal ecosystem.

Documenting change over time is a recurring theme in marine research. To gain insights into day-by-day variations in the excruciatingly slow-paced lives of some benthic animals, in 1993 institute researchers deployed a time-lapse video camera on the seafloor over a month-long period. An extended video record of the behavior of clams revealed that although they lead pretty boring lives by human standards, they are occasionally quite active. The clams reposition themselves in the sediments to optimize their access to chemical compounds which are essential to their survival.

To overcome difficulties in measuring images underwater, MBARI engineers devised a tool that uses laser-generated reference points to calculate the distance and tilt of the seafloor relative to an ROV. From these measurements, a two-dimensional grid can be projected on an image. This quantitative system, installed on *Ventana's* camera housing in 1995, assists researchers in determining the sizes of individual animals, the numbers per unit area in a population, and the scale of geologic features.

Interdisciplinary studies on cold seeps are a prime example of MBARI's capacity to respond opportunistically when intriguing prospects for new avenues of research arise. Initially discovered on the Florida Escarpment in the 1980s, cold seeps are often found on continental margins. The active boundary between the Pacific and North American plates, which runs from Cape Mendocino to the Gulf of California, is one such setting. Unlike either the plate boundary section to the north, where the Pacific plate subducts beneath its North American neighbor, or the Gulf of California to the south, where new crust is being created, the Central California stretch of the boundary is a transform margin. This complex area of the margin spans more than

Chemosynthetic bacteria are contained in the gills of cold-seep clams, such as Calyptogena pacifica *(above) and* Calyptogena packardana, *a species discovered by MBARI scientists and named for David and Lucile Packard.*

100 kilometers (62 miles) and includes the San Andreas, Monterey Bay, and San Gregorio fault zones. Powerful tectonic forces are grinding the opposing plates against each other from northwest to southeast, a mechanism referred to as strike-slip faulting. To a lesser degree, the movement of the plates also compresses their edges, producing faults, folds, and uplifted structures.

In 1988 cold seeps were found about 50 kilometers (31 miles) offshore in the Monterey Fan Valley, at the base of the continental slope at a depth of about 3,000 meters (9,800 feet). Evidence hinting that such underwater springs might also be found in the bay turned up in ship-dredged material containing shells of clams associated with seeps. Side-scan sonar surveys within Monterey Canyon by Lamont-Doherty Geological Observatory in the late 1980s had shown areas of high reflectivity on canyon walls and the seafloor. Investigating these leads with *Ventana*, institute scientists discovered vigorous colonies of vesicomyid clams and grayish-white bacterial mats at five locations between 1991 and 1995. They also collected limestone crusts and "chimneys," formed by bacterial processing of methane, or natural gas. These tantalizing findings presented a chance to pursue MBARI's broad goal of understanding bay systems by closely examining one aspect of the bay environment: the workings of cold-seep communities and the geologic conditions that give rise to them.

As is common around the Pacific Basin, vesicomyid clams are the principal animals at Monterey Bay cold seeps. MBARI studies have revealed that the mechanism fueling life processes for these clams—including two species which are new to science—is chemosynthesis. Like their cousins at hydrothermal vents on mid-ocean ridges, seep clams harbor bacteria that use energy derived from hydrogen sulfide. The bacteria thrive in the tissues of the clams, close to their energy source and protected from predators, and in turn they produce nourishing compounds for their hosts. Other chemosynthetic organisms at the seeps include extensive mats of free-living *Beggiatoa* bacteria and, rarely, vestimentiferan worms. Thus, in contrast with most life on Earth, cold-seep communities exist independent of sunlight. Cnidarians, gastropods, crabs, brachiopods, and other more common seafloor animals also inhabit seep communities.

Scanning electron micrograph of Thioploca *bacteria, chemoautotrophic organisms found at some cold seeps.*

Where do cold-seep fluids originate? How do fluid processes relate to events on land?

Institute researchers have found that the chemical composition of seep fluids, which varies according to fluid origins and history, controls which species of clams, and perhaps other animals, are able to thrive at individual sites. For example, *Calyptogena pacifica* is most abundant at low-sulfide seeps, while *C. kilmeri* thrives where sulfide concentrations are high. Each has adapted physiologically to certain environmental conditions, which allows them to divide the available resources. Defining ecological relationships such as these helps MBARI scientists assemble a clearer picture of seafloor communities.

Many of the complex relationships yet to be unraveled pertain to organisms living just beneath the surface of the seafloor—a realm of life-forms so diverse and plentiful that researchers suspect they may comprise the majority of the biomass at the ocean bottom. Equally significant, organisms beneath the seafloor are likely responsible for many of the chemical reactions occurring between sediments and seawater. One group of such agents is the *Thioploca* bacteria, which were discovered at Monterey Bay cold seeps in 1996. Previously known only in oxygen-depleted waters off Chile, these bacteria are suspected to be key players in the chemical cycling of carbon, nitrogen, and sulfur.

The manipulator arm on Ventana *can grab a softball on one of these push-core devices, then push the tube into the seafloor to collect sediments.*

When scientists determined the source of hydrogen sulfide for bay seep communities to be the chemical-rich fluids

Dan Orange, Norman Maher, and Gerry Hatcher examine a carbonate chimney fragment recovered from the Monterey Canyon.

leaking from the seafloor, a new set of questions arose: Where do the fluids originate? What controls where and how the fluids are expelled? Are faults the major conduits for transporting fluids from below the seafloor? How fast are fluids discharging, and how do fluid processes relate to events on land? These questions on the plumbing system beneath the bay prompted technological innovations at MBARI to improve the gathering of geological information.

Underwater saws and a rock hammer were adapted for attachment to *Ventana's* manipulator arm to hew chunks of rock from geological features of interest. For collecting soft sediments, institute researchers and engineers developed a series of push-corers. A hydraulic version, mounted on *Ventana's* frame is designed to extract vertical sections up to two meters (6.6 feet) long. Back at the MBARI laboratory, geologists squeeze the fluid out of the spongy cores and evaluate their chemistry. The samples divulge important clues about rates of sediment formation and chemical changes in the pore waters within the sediments. Geologists also glean information from different sections (depths) of the cores about the types of foraminiferans that thrived in the past. When these minute protozoans perish, their hard shells sink to the seafloor and become part of the sediments. From the kinds and numbers of foraminiferans present in a sample scientists can infer the environmental conditions that prevailed in a past era.

Another specialized apparatus which originated at the institute is the benthic barrel. It gauges the flow rates of cold-seep fluids and can be adapted to analyze temperature and chemical changes over time. MBARI engineers also modified the design of a submarine geocompass and adapted it for use on institute ROVs. This device measures the orientation of major bedding planes, or strikes and dips, of sedimentary rocks. Such measurements, mapped over large areas, allow researchers to decipher faults, folds, and other structures that help explain the geologic history of a region.

Using these and other tools, MBARI scientists are carrying out the first study of widespread fluid expulsion at a transform margin. With collaborators, they have analyzed the distinct chemical signatures of bay cold-seep fluids and

The corehole seismometer is placed in a housing (on left), and the entire package is cemented in a corehole on the seafloor.

identified three possible sources. In the Santa Cruz Mountains northeast of the bay, rainfall percolating through the ground may flow through tilted aquifers to the base of Monterey Canyon. The soft sediments of the bay, which yield copious amounts of water as they are compacted into rock, are another likely source. And, the Monterey Formation, a layer of ancient seafloor several kilometers beneath the bay, may exude fluids due to the weight of overlying rock layers pressurizing and heating organic-rich contents. Overall, the rates of fluid seepage appear to be lower than those at plate margins that are actively converging and seepage rates at passive margins where sediments accumulate rapidly.

Cold-seep plumbing is only one facet of Monterey Canyon's geology that MBARI scientists are probing. Institute scientists also have started to decode layer by layer the complex record embodied in the deepest submarine canyon along the continental United States and its branching side canyons. In 1992, employing the diamond-drill coring system developed by MBARI and collaborators at the Ocean Drilling Project, they collected cores of granite and deformed sediments from canyon walls. The more powerful, four-barreled rock corer refined two years later at MBARI has permitted more extensive sampling. As of 1997, institute researchers had collected more than 35 drill-cores of sandstone, carbonate, granite, and basalt, which have been analyzed for chemistry, mineral composition, and age by a variety of techniques.

Striving to pin down the fundamental contacts between rocks of differing ages and origins, institute geologists drilled a series of granite cores in the bedrock of Monterey Peninsula, from the southeastern-most point of the main canyon's southern meander to the west wall of Carmel Canyon, a side branch. While the findings from these cores are still being evaluated, analysis of drill cores from Soquel Canyon (on the opposite side of the main canyon) suggest that the rock there is considerably older than the Monterey Formation sediments to the southwest. These discoveries will help researchers map the geologic history of the area and derive a new model for the canyon's formation.

Ventana bears an electronic data-logger (yellow sphere) similar to one used in the MOISE experiment.

A significant spin-off benefit from the core drilling occurred when researchers realized that the coreholes would make ideal sites for the installation of seismic instruments to monitor earthquakes and other physical events from the seafloor. Inserted into the holes and firmly in contact with the surrounding rock, the instruments are positioned to accurately record seismic signals. In 1996 MBARI scientists deployed seismometers in coreholes at two canyon sites. The instruments were recovered nearly four months later, along with a record of data that included events undetected on land, such as very small tremors, underwater landslides, and vocalizations from passing whales. The successful deployment represented one of the longest continuous ocean-bottom seismometer experiments on record at that time.

In 1997 institute scientists, with collaborators from France and the University of California, took the concept of continuous seafloor seismic monitoring a big step further. In the Monterey Bay Ocean Bottom International Seismic Experiment (MOISE), they used *Ventana* to emplace a broadband seismometer so sensitive it can "feel" the tides. These instruments and others capable of recording both local and global events were left on the seafloor for three months. An advanced data-logger, designed at the institute for long-term experiments and greater flexibility in ROV missions, was later added to the MOISE suite.

Data from the MOISE site, on the western side of the plate margin, will complement that from land-based seismic stations to the east. This will assist scientists to determine with greater accuracy the location of seismic events seaward of Central California. The results from the MOISE instruments will be compared with those from conventional ocean-bottom seismometers and with the instruments adapted for deployment by ROV. The consequences of these efforts will, hopefully, include new technology to share with the marine seismology community and the eventual development of seafloor observatories to augment the existing global seismic network.

Regional marine geologic processes, the workings of benthic communities, and development and implementation of technology for seafloor seismic monitoring will

To improve traditional methods of archiving deep-sea samples, an MBARI database will integrate each sample with data from the collection site and subsequent analyses.

doubtless remain fundamental areas for MBARI ocean-bottom research. At the same time, as the institute flexes new muscles with powerful ocean hardware that allows penetration not only of Monterey Bay's greatest depths but also distant waters, unanticipated opportunities will surely arise from the benthic cosmos.

M. Leet for MBARI

Three elements were added to MBARI's infrastructure: a modern science-engineering-administration complex, a second research vessel, and a revolutionary underwater vehicle.

Chris Grech and Lisa DeQuattro work in the science control room of the R/V Western Flyer.

Coming of Age

By 1990 science and engineering initiatives were in full swing at the institute. At the end of June Richard Barber resigned as executive director and returned to Duke University with the board of directors' appreciation for navigating MBARI through its first two-and-one-half years. Technical Director Mike Lee stood in as interim executive director while the hunt for a permanent one proceeded. In January 1991 Peter Brewer, a chemical oceanographer from the Woods Hole Oceanographic Institution, took up the post. During Brewer's term as president and executive director, three crucial elements were added to MBARI's infrastructure: a modern science-engineering-administration complex, a second research vessel, and a revolutionary underwater vehicle. Together these assets markedly expanded the institute's capabilities and strengthened its standing in the oceanographic community.

MBARI's work force numbered 55 when Brewer took the helm. The institute's 1,486-square-meter (16,000-square-foot) building in Pacific Grove—never luxurious—was becoming crowded with people and equipment. The second floor was sagging and lab space was at a premium.

The need for additional space had been somewhat alleviated when a new operations facility and dock were constructed in 1989 in Moss Landing, halfway around Monterey Bay. The relocation of operations there split the institute into two campuses, some 32 kilometers (20 miles) apart by road. But much was gained with the new 2,323-square-meter (25,000-square-foot) building that provided ample space for a general-purpose machine shop and several other specialized shops, as well as room for working on submersibles, moorings, and other oceanographic equipment. The facility also included offices for operations staff as well as seawater and cold labs for live animal specimens. The *R/V Point Lobos* took up its berth in Moss Landing Harbor, and research expeditions from the head of Monterey Canyon commenced.

David Packard remained intimately involved in day-to-day operations at the institute. Practicing "management by

Packard's goal for MBARI to become a first-class research institute demanded a ship and an ROV that would embody the cutting edge of oceanographic technology.

walking around"— his trademark style at Hewlett-Packard Company—he would drop in unannounced at Pacific Grove administrative offices to discuss tasks and provide guidance. He also often stopped by the Moss Landing machine shop to check on the progress of projects. Packard's impatience and high standards were well known. He did not hesitate to telephone researchers and demand an explanation, for example, of why a particular instrument was utilizing a certain frequency, or to comment on an engineering design.

On the other hand, Packard also made a habit of appearing at MBARI offices on weekends and expressing encouragement and thanks to staff working overtime. And in the early years he sponsored several summer fishing trips to Lake Tetachuck in British Columbia. These staff retreats helped to develop a sense of camaraderie at the fledgling institute. In sum, Packard's incisive intellect, hands-on participation, generosity, and vision imbued institute staff with loyalty, respect, and deep affection for the institute's founder.

Packard's goal for MBARI to become a first-class research institute demanded a ship and an ROV that would embody the cutting edge of oceanographic technology. He saw the *R/V Point Lobos* and *Ventana*—despite their standard-setting performance records—as learning tools for a newer generation of custom-built oceanographic hardware.

From the start, discussions about a new ship centered on a design originally derived from U.S. Navy plans for offshore supply platforms in the latter years of the Vietnam War. Abbreviated SWATH, for "small waterplane area twin hull," its distinguishing features are a broad superstructure supported by relatively narrow vertical struts connected to a pair of submerged, torpedo-like hulls. The design places very little displacement or buoyancy at the ship's water line. This, together with the ship's computerized motion control system, renders the vessel relatively immune to the impacts of water motion and, therefore, up to five times more stable than mono-hulled ships while underway.

The institute's dock at Moss Landing had been built specifically to accommodate a SWATH vessel. In 1990 Derek Baylis, the project engineer, drew up specifications for what was to be an all-aluminum ship dedicated to ROV missions in the bay. Requests for construction bids went out, and

Greg Pio for MBARI

The center well or "moon pool" of the R/V Western Flyer *is customized for launching the ROV.*

Packard was reviewing vendor presentations when Peter Brewer took up the MBARI directorship. Brewer argued successfully for significant modifications to the plans, in particular an increase in the number of berths and expansion of laboratory space, which would make possible extended voyages and significant scientific experiments.

An important feature of the final ship design was its diesel-electric plant for meeting power needs. Five diesel engines, housed in the SWATH vessel's twin submerged hulls, drive electric generators for DC-propulsion and thruster motors. This arrangement provides a generous supply of power with high fuel efficiency even when the vessel is stationary, and it increases the flexibility in allocating power for ship needs. Diesel-electric propulsion systems had long been employed on large ships, but not on smaller vessels. Packard was curious to see if such a system, despite its substantially greater weight than alternative propulsion systems, would be effective for a mid-sized ship. In short, it was an experiment which, if it worked, might prove the efficiency of diesel-electric for even smaller research vessels.

Also uncommon for submersible-equipped research vessels, the new ship was built with a center well—called a "moon pool"—between its two hulls. The moon pool serves as the launching point for deploying ROVs and other instruments. A crane lifts up the ROV and, after the moon pool accordian doors open to the sea below, the crane lowers the submersible into the water, then retrieves it following a dive. Adjacent to the moon pool, a cable-handling system controls the tension of the ROV tether. As the vehicle carries out its mission, the head of the crane—through which the tether is paid out—bobs up and down to compensate for ship motion. This diminishes stress on the heavy tether and decreases its movement in the water.

Tank tests on SWATH models were completed in autumn of 1991, and a contract was negotiated with SWATH Ocean Systems of San Diego, California for construction of a ship designed to weigh less than 500 gross tons. Delivery of the vessel was projected for late 1993. Packard stated enthusiastically that he expected the ship would be "the most advanced vessel of its kind." With a range in excess of 2,500 nautical miles, the SWATH would make possible the

The *R/V Western Flyer* is designed to provide the most stable platform conceivable for supporting ROV operations.

MBARI's second executive director, Peter Brewer, stands before the R/V Western Flyer *prior to launching in San Diego.*

expansion of MBARI's research to the world's oceans, thus furthering the institute goal to "go deeper and stay longer."

As is often the case with one-of-a-kind construction projects, particularly those which incorporate pioneering technology, the SWATH project took on a life of its own. There were modifications, delays, contract difficulties, and cost overruns as the design for a new ROV converged with the ship's blueprints. MBARI personnel stepped in to consult on the ship layout and equipment needs. At long last, the finished, Coast-Guard-inspected vessel—36 meters long and 16 meters wide (117 feet long and 53 feet wide), with accommodations for 26 crew and scientists—reached its new berth in Moss Landing on February 2, 1996. It was christened the *R/V Western Flyer*, after the wooden ship which carried Monterey biologist Ed Ricketts and writer John Steinbeck on their expedition to the Sea of Cortez in 1940.

For all the frustration and challenges of its construction era, the *R/V Western Flyer* emerged as a vessel distinguished by a design dedicated to providing the most stable platform conceivable for supporting ROV operations. Every aspect of its infrastructure—from the science control room and the computing network to the ship's automated monitoring system—were arranged to facilitate ROV missions. While none of the *R/V Western Flyer*'s components is, by itself, unique, the vessel as a whole combines the most sophisticated instruments and technologies available, giving it the potential to carry out missions that would normally be the work of larger ships with bigger crews.

Concurrent with the planning and building of the SWATH ship, Packard and Brewer faced the pressing need for larger facilities. In January 1991 they learned that a four-acre parcel of ocean-front land with a pier, formerly owned by General Fish Company, would be offered for bid at a public auction in Moss Landing. Situated adjacent to the institute's operations facility built two years earlier, the property offered the opportunity to relocate the science and administrative divisions, consolidating the institute at the head of Monterey Canyon. In short order MBARI acquired the parcel, leased the pier to a fish-buying business, and razed the old and decrepit General Fish buildings. Architects drew up a design for an E-shaped, 6,500-square-meter (70,000-square-foot) building with spacious labs surrounded

by offices on the building's perimeter, overlooking the bay and the harbor.

In February 1994 ground was broken for construction of the new building. Before the structure was erected, geotechnical engineers fortified the building site. The 1989 Loma Prieta earthquake had revealed Moss Landing's vulnerability to seismic damage. The powerful shaking of that event had caused the sandy, porous earth to behave like a liquid, completely destroying the neighboring Moss Landing Marine Laboratories facility. To reduce future chances of such a catastrophe on MBARI property, engineers increased the density of the earth at the site. First they used a massive vibrating probe to eliminate air spaces between sand particles. Then they filled in the area with 14,000 tons of gravel and drove more than 400 steel "H" pilings into the stabilized earth. These embedded pilings were tied to horizontal structural beams, further strengthening the building. To protect the building from punishing storm waves, a seawall at the site was enlarged, modified to deflect waves, and reinforced with a million pounds of steel.

The architects and designers took care to integrate the exterior design of the institute's headquarters with the

(counterclockwise, from left)
General Fish property in Moss Landing was purchased for MBARI's research facility site;
vibrating probe was used to eliminate air spaces in the soil at the building site;
400 H-beams were driven into the ground;
the building under construction.

adjoining harbor community. The building is largely of molded cement planking, and native plants and granite boulders grace the surrounding landscape. A variety of works by regional artists enhance its interior. The facilities also incorporate significant conservation features such as thermal glass; energy-efficient lighting systems; variable frequency drives on fans and pumps; and a computerized, building-wide, electric-power management system. MBARI facilities managers plan to install a thermal storage unit that will make large quantities of ice during off-peak energy hours. The stored ice will be used by day for cooling, thereby reducing the institute's operating costs by lowering its demands for expensive peak power.

In October 1995 MBARI received a major development award from the Monterey County Economic Development Council in recognition of the new headquarters. In November and December the science, engineering, and administrative staff left 160 Central Avenue in Pacific Grove and settled in the spacious quarters in Moss Landing. The total staff numbered just over a hundred.

MBARI's science, engineering, and administration building in Moss Landing was completed in late 1995.

There was extensive discussion between MBARI engineers and scientists about the vehicle's range of science missions and the basic capabilities necessary for carrying out those missions.

The major project of the institute's watershed years, conceived and initiated years before the new ship and facilities, was the engineering and building of the ROV *Tiburon*. While the SWATH and the new Moss Landing center of operations absorbed substantial financial resources, with mostly secondary impacts on MBARI personnel, the new underwater vehicle demanded the lion's share of the institute's engineering brain-power for several years.

The purchase of a commercial ROV for the institute's first submersible, *Ventana*, was the initial step to develop in-house an exclusively scientific platform specialized for supporting deep-ocean research. The month-in, month-out experience of operating and modifying *Ventana* provided invaluable technical contributions to the design of *Tiburon*.

An essential element of the early work on the *Tiburon* project was extensive discussion between MBARI engineers and scientists who were users of human-occupied submersibles as well as *Ventana*, in an effort to define the new vehicle's range of science missions and the basic capabilities necessary for carrying out those missions. The driving principle was to evolve a versatile vehicle capable of gathering samples and high-quality information about the deep sea as effectively as possible. A visiting international committee of engineers was called upon to review the design concepts and help finalize specifications for the new ROV. The resulting plan, which would require significant applications of pioneering technology, called for an electric-powered vehicle capable of descending to 4,000 meters (13,100 feet). A steel-armored, electro-optical umbilical connecting the ROV to the *R/V Western Flyer* would provide power for the vehicle and its instruments.

Years of painstaking work have made the plan largely a reality. Like its namesake, the shark, *Tiburon* is quiet, agile, and flexible. One of the most sophisticated all-electric ROVs currently being used for ocean science, its precision thrusters allow for high performance control while keeping underwater noise to a minimum. Extensive engineering efforts went into reducing vehicle disturbance—a property that biologists consider especially important. A variable buoyancy control system also helps to precisely manipulate vehicle movement at all depths. *Tiburon* can hover inches above the seafloor, without creating turbulence, to enable a

(from top to bottom)
The Tiburon *prototype, made of redwood, was built in 1992 and tested for two years;*
Gary Burkhart crafts an aluminum frame for the final vehicle;
Jim McFarlane works surrounded by the syntactic foam pack that forms part of the vehicle's flotation system.

pilot to pluck a rock sample, for example. And, it can manuever quickly to track animals. Video images are recorded by two high-resolution video cameras mounted on the front of *Tiburon*. Its powerful lights can illuminate an area more than 270 degrees wide and operate in unison with camera movements. Other lights and cameras allow shipboard scientists perspectives in all directions from the ROV.

A chief design goal has been to maximize *Tiburon's* flexibility for deep-ocean science. The core vehicle is equipped with a suite of built-in sensors, imaging sonar, a manipulator arm, an acoustic navigation sytem, and an acoustic doppler velocimeter that allows scientists to determine both water velocity and the vehicle's speed. For versatility the aluminum frame was crafted to attach quickly and easily to modular toolsleds. These packages of sensors and tools can be left on the seafloor for experiments or used for specialized tasks such as seafloor surveying and mapping, benthic ecological and geological studies, and midwater observation and collection.

One of *Tiburon's* most defining characteristics, again in common with its namesake, is its "intelligence"—largely a product of the ingenuity of the institute's computer engineers. The computing hardware and software architecture rely on a half-dozen data concentrators and peripheral computers that collect data from many types of instruments and sensors and process it independently. The derived information is then relayed to a data manager and the main computer, which transmits it shipboard. There the data are uncompressed and distributed to various user stations. The computer architecture developed by the *Tiburon* team is designed such that if problems should occur in one part of the system, they will not cripple operations in the rest of the system.

A prototype of the *Tiburon*, which served as a platform for evaluating key components and computer software, was built in 1992 and tested during the following two years. The final vehicle frame was completed in early 1995. Scientific sensors, electronic components, and sub-systems were installed and integrated on the core vehicle. A pressure-tolerant, syntactic foam pack was added as part of the vehicle flotation system that makes *Tiburon* neutrally

A chief design goal has been to maximize *Tiburon's* flexibility for deep-ocean science.

buoyant in seawater. Constructed of tiny glass spheres embedded in epoxy, the foam pack is painted in bold yellow, with stripes of blue and white and an emblematic shark.

Throughout 1997 *Tiburon* has been tested, fine-tuned, and integrated into the workings of its mother ship—a marriage which, like most, requires effort. Meanwhile, ROV pilots and scientists have honed their skills at operating the sophisticated systems that make the *R/V Western Flyer* and its underwater mate a unique oceanographic team. The new hardware has not replaced MBARI's older workhorses, as the *R/V Point Lobos* and the ROV *Ventana* maintain a solid niche

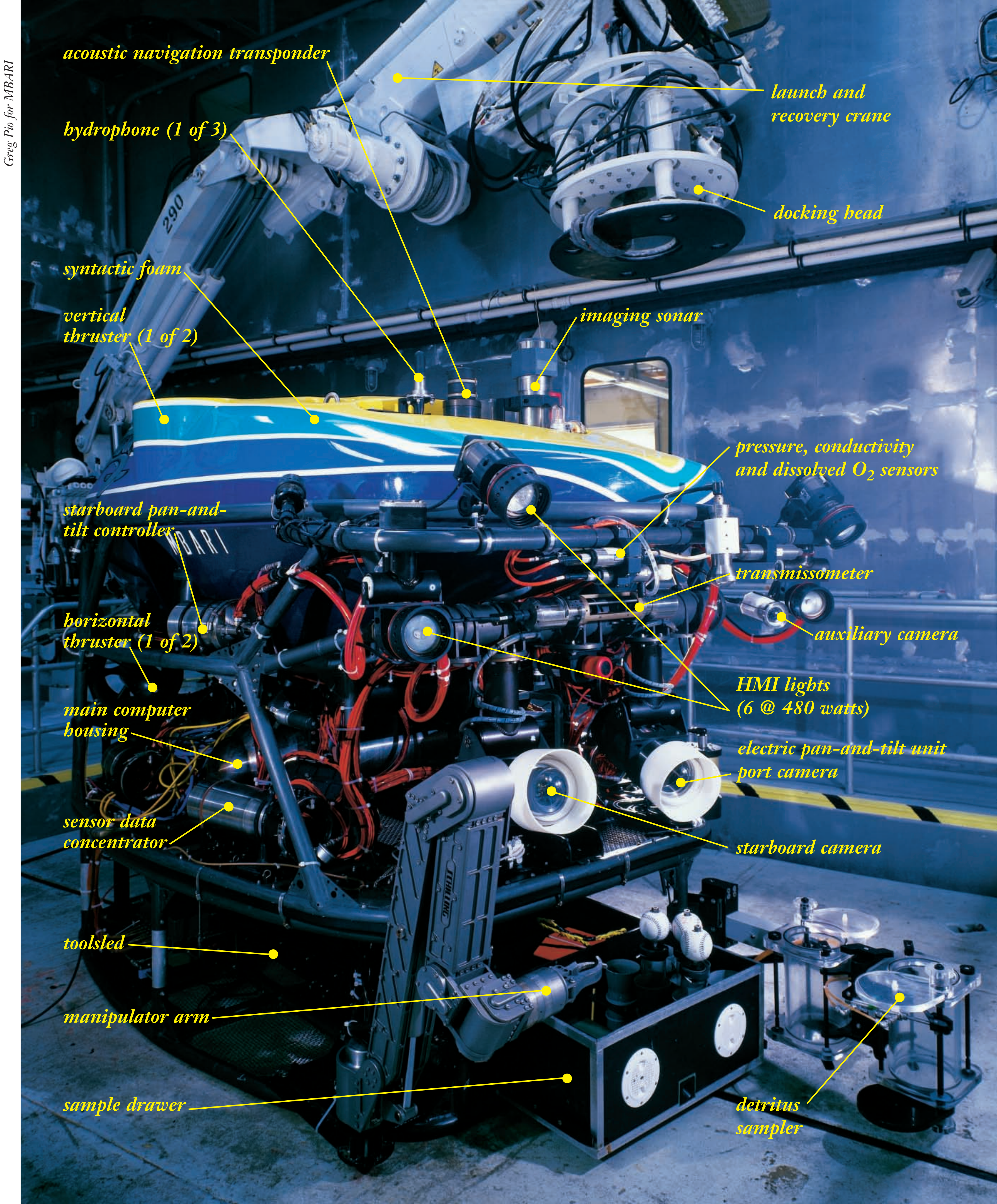
Late stages of Tiburon *development included extensive testing in a tank formerly used by the Monterey Bay Aquarium for keeping tuna for exhibits.*

in the institute's Monterey Bay operations. Rather, the new ship and ROV will take MBARI deeper and further into the ocean world, in accordance with the institute's decade-old guidelines.

On March 26, 1996 David Packard died at the age of 83. Among a long list of accomplishments he had established MBARI, nurtured it through its early years, and maintained a strong presence at the institute throughout its coming of age. He had lived to see the trio of watershed efforts that he had personally set in motion come to fruition. The growing MBARI staff was at home in comfortable modern quarters, the *R/V Western Flyer* docked within sight, and *Tiburon* was undergoing sea trials. In a champagne-bottle-breaking ceremony early in March, Packard had christened the *R/V Western Flyer*, with Tony Berry, captain of the original *Western Flyer* looking on. Just prior to his death, Packard took his one and only ride on the *R/V Western Flyer*—appropriately, from Moss Landing to Monterey and back.

David Packard with prototype of Tiburon.

Greg Pio for MBARI



M. Leet for MBARI

Nancy Jacobsen annotates images from the institute's video archives.

An important goal of the institute has been the sharing of the knowledge gained about the deep sea with the general public, students, and the wider scientific community.

Collaborations and Outreach

Since its inception MBARI has collaborated on scientific studies with other researchers. Likewise, an important goal of the institute has been the sharing of the knowledge gained about the deep sea with the general public, students, and the wider scientific community.

Much of MBARI's outreach to the general public has been facilitated by the institute's close and unique relationship with the Monterey Bay Aquarium. Over the past decade MBARI staff have helped to collect many animals for aquarium exhibits, and researchers have served as lecturers and curriculum consultants for the aquarium's youth and interpretive programs. MBARI staff members have also participated in the aquarium's Syllabus and Instructional Materials Development Project (SIMS) for the Future of the Oceans Initiative. Institute scientists have contributed to aquarium exhibits, books, and videotape narratives on a variety of topics, such as jellies, kelp forests, seashore life, octopuses and squids, and the Monterey Bay National Marine Sanctuary.

The aquarium and MBARI also have collaborated with the Monterey Peninsula Unified School District; California State University, Monterey Bay; and the University of California, Santa Cruz, on an experimental, innovative electronic outreach program known as "Virtual Canyon." A two-year grant from the National Science Foundation, beginning in September 1995, supported teachers and students in the design, development, and assessment of a prototype "electronic field trip" to the Monterey submarine canyon that is accessed through the World Wide Web. The Web site offers young students the opportunity to join MBARI research on the canyon's deep-sea habitats. The online learning system allows K-12 students to conduct science projects in a virtual canyon and research laboratory and post their methods and findings on the Web for the benefit of themselves and other students.

In 1997 MBARI developed and coordinated its first official summer internship program, hosting 13 university-level students from around the country, who shared activities

(top) Institute staff have contributed to videos and publications of the Monterey Bay Aquarium.

(bottom) OTTER (Ocean Technology Testbed for Engineering Research) resulted from a multi-year collaboration between MBARI and Stanford University's Aerospace Robotics Laboratory.

with participants in the aquarium's internship program. Other commitments to higher education over the last decade have included support for more than two dozen students who completed various academic degrees working with institute staff. Also under MBARI auspices, 16 post-doctoral fellows have each conducted two to three years of research at the institute. MBARI scientists have taught at undergraduate and graduate levels at regional universities as well. In addition, the institute and the aquarium have co-hosted professional scientific meetings, such as Jellyfest 1992 and the Eighth International Deep-Sea Biology Symposium in September 1997.

Forging links with academic institutions also has been a priority at the institute. For example, since 1991 MBARI engineers have collaborated with Stanford University's Aerospace Robotics Laboratory (ARL) to advance the technology of robotic vehicles used in ocean exploration. The partnership has focused on improving control systems, both for general vehicle navigation and maneuvering and for precision manipulation of robotic devices for performing tasks in the viscous ocean environment. Together MBARI and ARL built a demonstration platform, the Ocean Technology Testbed for Engineering Research (OTTER) for research in real-time vision sensing, underwater manipulator control, and thruster dynamics. Results from this program are already enhancing the effectiveness of the vehicle-operator team that blends the human capabilities of judgement and decision with the accuracy and speed of machine computation and control.

In 1992 MBARI joined the University of California, Santa Cruz, and the Naval Postgraduate School in Monterey, California, in launching the Real-Time Environmental Information Network and Analysis System (REINAS). A network of instruments for collecting a range of data, REINAS provides information on past, current, and predicted oceanographic and meteorological conditions in the Monterey Bay region via the World Wide Web. The first demonstration project, led by institute researchers, was a study of the circulation of sea-breezes and land-breezes and their effects on the coastal ocean. MBARI's moorings, M1 and M2, provide continuous real-time data from instruments such as the acoustic doppler current profiler, surface

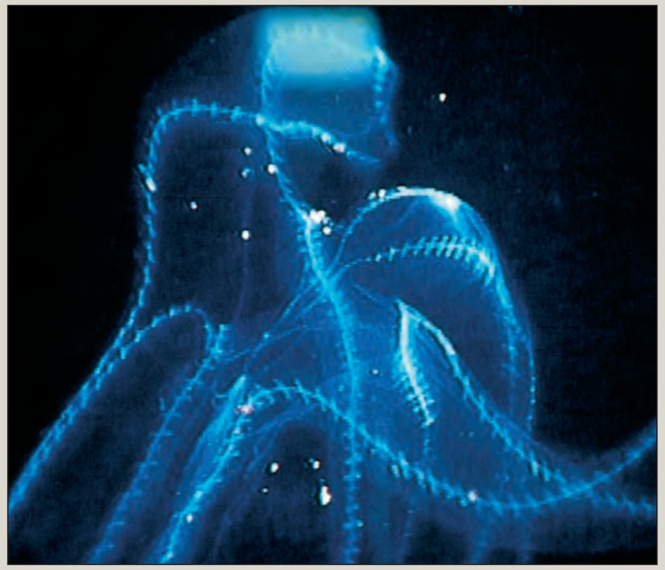
Mark Pickerill and Hans Jannasch hold a nitrate OsmoAnalyzer, on their way to installing it on the Hawaii Ocean Time series buoy, in 1997.

CTD (measuring temperature, salinity, and depth), and sea-surface weather station.

Other MBARI professional and scientific liaisons extend across national boundaries. In 1990 institute scientists conducted investigations on the biology and geology of cold seeps in Sagami Bay, Japan. It was the first of a series of cultural and scientific exchanges that were solidified in 1994 by an agreement with Japan Marine Science and Technology Center (JAMSTEC) to cooperate in research comparing Monterey and Sagami bays. Similarly, since 1990 the institute has exchanged technical information on computer architecture and engineering for ROVs with the French oceanographic center Institut Français de Recherche pour l'Exploitation de Mer (IFREMER).

Information specialists from the institute led efforts in the mid-1990s to establish the Monterey Bay Region Futures Network. Under network auspices, more than $4 million from multiple granting agencies funded the purchase of high-speed communications infrastructure to serve regional universities, research institutions, K-12 educators and students, and Monterey Bay National Marine Sanctuary managerial staff. The collaboration also resulted in thousands of hours of expertise being donated by MBARI staff and other information specialists toward the design of an information and communications network for the region.

MBARI's efforts to share the skills and knowledge of its staff, the results of institute research, and new knowledge gained about the deep sea reflect its mission. There is a clear recognition that collaboration and outreach regionally, nationally, and beyond are essential to making a long-term contribution to the knowledge of world oceans.



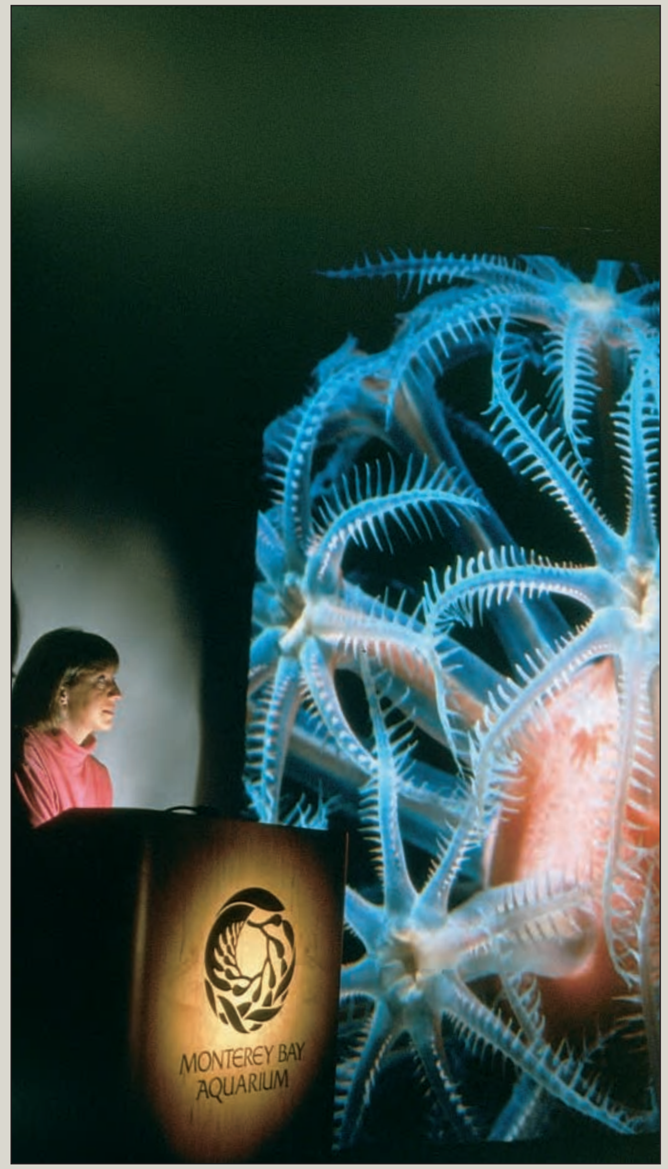
Kiyohimea usegi, a lobate ctenophore, was described by MBARI scientists in 1992 from specimens discovered in Monterey Bay.

LIVE FROM MONTEREY CANYON

MBARI's special relationship with the Monterey Bay Aquarium has provided unique opportunities to educate the public about oceanographic research. Since 1989 the institute and the aquarium have collaborated on an educational program that uses technology and live video images from the ROV to give the public a peek over the shoulders of MBARI scientists at work.

The prototype *Live from Monterey Canyon* program was developed as part of a one-week celebration of the aquarium's fifth anniversary in October 1989. Images from the ROV camera were relayed in real time from the ship to the aquarium by microwave broadcast signals. Inside the aquarium's auditorium, a projector displayed the live transmissions as two-by-four-meter images on a large screen. Interpreters from the aquarium described the research, communicated by radio with scientists on the ship, and answered questions from the audience. That anniversary was also marked by the Loma Prieta earthquake, which affected transportation and tourism in Central California so that the numbers of aquarium visitors temporarily declined. Nonetheless, the program drew in the local community and the aquarium staff, enthralled at the sight of habitats deep in the bay and excited to share the thrill of research with scientists. At the end of the trial, MBARI and the aquarium agreed to continue the collaboration and expand it so that on days when the ROV was not diving, interpreters could make presentations using previously recorded videotape.

In mid-1993 MBARI engineers installed a microwave link to Mount Toro, 35 kilometers (21 miles) from Moss Landing. The link greatly improved the quality of the live video signal and extended the range of signal reception to about 100 kilometers (60 miles) from the location of image recording. The microwave and other technology made the program more adaptable to



Judith Connor, in the Live from Monterey Canyon *program, interprets the wonders of the deep to an audience at the Monterey Bay Aquarium.*

different audiences and interests. An electronic podium with a computer touch-screen was installed to access illustrations and segments from the institute's library of 3,000-plus hours of underwater videotape. These state-of-the art visual aids enhance the interpreter's descriptions and enrich the visitor's experience.

Audience participation in *Live from Monterey Canyon* has been active and enthusiastic. Thousands of aquarium visitors have watched, questioned, and delighted in the beauty and excitement of deep-sea research. The program is dynamic and variable—each day's program is unique. Like the research itself, *Live from Monterey Canyon* continues to evolve and develop with advances in information and technology. The skill and enthusiasm of the interpreters are large ingredients in the program's success as well. Over the years more than three dozen aquarium and institute staff members have volunteered as "linkers."

In May 1995 *Live from Monterey Canyon* played to a larger audience in Washington, D.C., that included the U.S. secretaries of commerce and education and 450 other supporters of the information super-highway. Soon afterward, an initiative of the California Research and Education Network (CALREN), in which MBARI collaborated, brought the live transmissions to the San Jose Tech Museum. These long-distance broadcasts utilized Asynchronous Transfer Mode (ATM) digital technology to share live video of undersea imagery from Monterey Canyon with far-flung audiences. *Live from Monterey Canyon* uniquely demonstrates both the pioneering research MBARI engages in and the virtually boundless opportunities for sharing it with the world at large.

External Projects and Outside Collaborations (1987-1997)

Europe, Africa, Asia, and the Western Pacific

1. **Scotland** 1997 — Research using MBARI-designed DNA probes for *Pseudo-nitzschia* and *Alexandrium*

2. **Netherlands** 1994 — MBARI-designed DNA probes used for research on toxic algae from the Wadden Sea (with University of Groningen)

3. **Issy-Les-Moulineaux, France** 1990 - 1997 — Technical and engineering exchanges with Institut Français de Recherche pour l'Exploitation de Mer (IFREMER)

4. **Sweden** 1997 — Research using MBARI-designed DNA probes for *Pseudo-nitzschia* and *Alexandrium*

5. **Baltic/ North seas (transition area)** 1990 — Water-monitoring cruise (for Danish Ministry of Environment)

6. **Rome** 1997 — Collaboration on quantitative video techniques (with University of Rome)

7. **Black Sea** 1988 — Study of suboxic and anoxic waters (with University of Washington and Woods Hole Oceanographic Institution)

8. **Lake Malawi, Africa** 1993 — Study of water column fluxes of carbon, silica, and detrital material

9. **Zanzibar, Africa** 1997 — Identification of toxic plankton (with Marine Research Center of the University of Dar es Salaam)

10. **Indian Ocean** 1995 —Study of primary production as related to carbon fluxes (NOAA Long Line Cruise)

11. **Heard Island, Indian Ocean** 1994 — Feasibility test for Acoustic Thermometry of Ocean Climate program; Monterey Bay was one of 11 sites for acoustic signal reception

12. **Lake Baikal, Siberia** 1991 — Water column study on fluxes of carbon, silica, and detrital material

13. **Hong Kong** 1997 — Research using MBARI-designed DNA probes for *Pseudo-nitzschia* and *Alexandrium*

14. **Sagami Bay, Japan** 1991-1997 — Midwater and benthic ecology studies on Sagami and Monterey bays (with Japanese Marine Science and Technology Center [JAMSTEC])

15. **Yokosuka, Japan** 1992-1996 — Collaboration on engineering design of an ROV (with JAMSTEC)

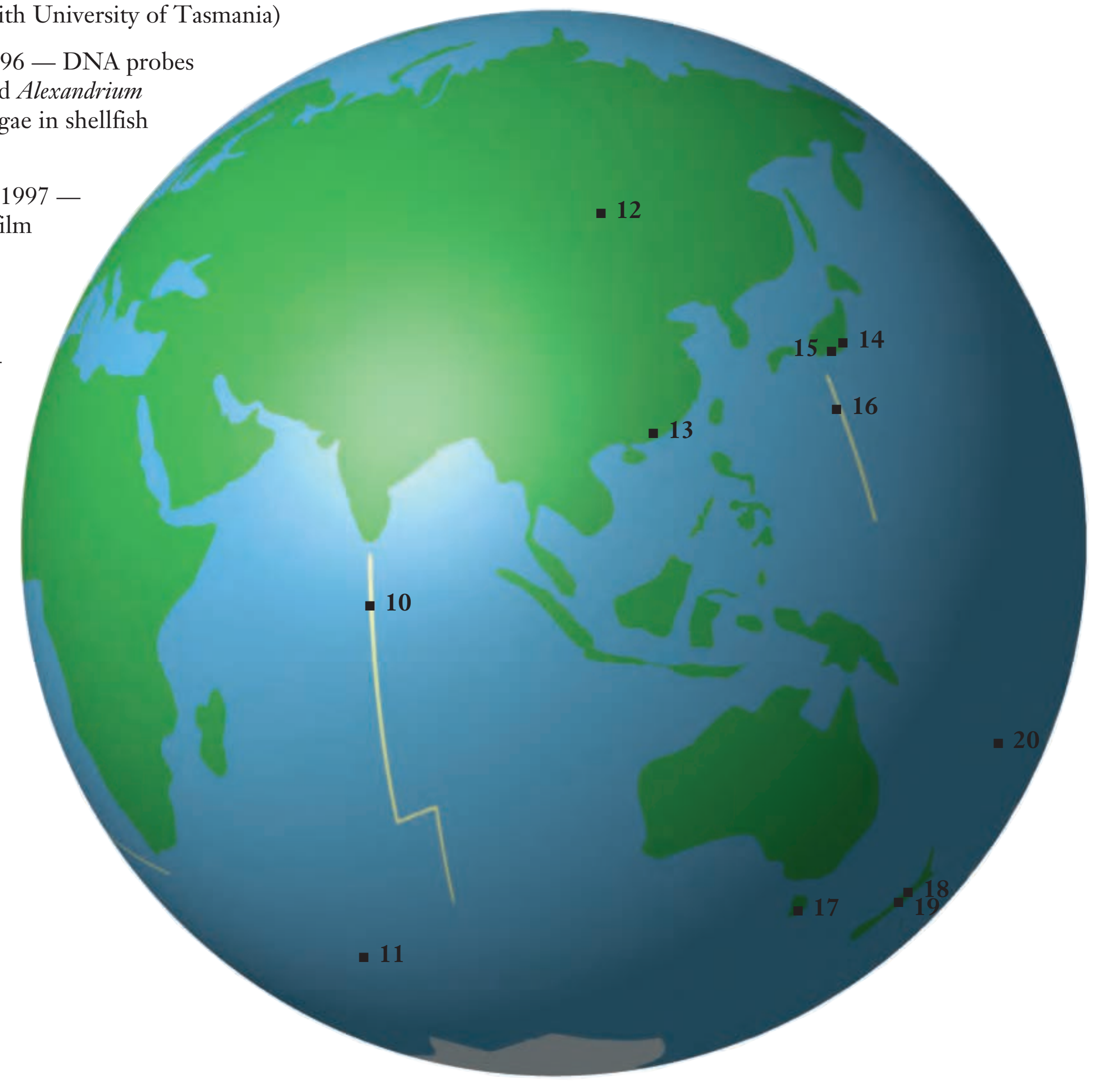
16. **Mariana Trench, Western Pacific** 1997 — Survey and sampling the Mariana Trench using the ROV *Jason* and testing of GIS-ARCView system (with University of Hawaii, University of Alaska, Rutgers University, and University of California, Santa Cruz)

17. **Tasmania, Australia** 1992-1993 — Feasibility study on DNA-based laboratory tests for *Alexandrium* dispersal in ships' ballast water (with University of Tasmania)

18. **Nelson, New Zealand** 1996 — DNA probes for *Pseudo-nitzschia* and *Alexandrium* used to detect toxic algae in shellfish farms

19. **Kaikoura, New Zealand** 1997 — Efforts to locate and film *Architeuthis*, the giant squid (with National Geographic Society)

20. **Southern Ocean** 1996 — Studies on primary production as related to carbon fluxes (NOAA Long Line Cruise)



Central and Eastern Pacific

21. Hawaii 1997 — Nitrate OsmoAnalyzers installed on Hawaiian Ocean Time series (HOT) mooring (with University of Hawaii)

1996 — OsmoSamplers placed at hydrothermal vents atop Loihi Seamount (with University of Hawaii and the National Undersea Research Program)

1996, 1997 — Research dives on Loihi Seamount using the *Pisces V* submersible (with University of Hawaii, the National Undersea Research Program, and others)

22. Tahiti 1995 — Preparation of the Scripps Oceanographic Institution ship *R/V Melville* for the IronEx cruise

23. Equatorial Pacific 1992 — Studies on primary production as related to carbon fluxes (NOAA Long Line Cruise)

1996-1997 — Nitrate OsmoAnalyzers placed on two TOGA-TAO moorings (with NOAA)

24. Aleutian Trench, North Pacific 1996 — Studies on fluid flow and tectonics at the toe of the Aleutian accretionary complex (with Rutgers University and GEOMAR)

25. Dabob Bay, Washington 1995 — Study on fecal pellet flux during diatom bloom (with University of Washington)

26. Washington (coastal waters) 1997 — Natural blooms of *Pseudo-nitzschia* and *Alexandrium* detected with DNA probes (with National Marine Fisheries Service)

27. Juan de Fuca Ridge (150 km off Oregon coast) 1996-1997 — Four OsmoSamplers placed in Ocean Drilling Project bore-holes on eastern flank of the ridge (with the National Undersea Research Program)

28. Central Cascadia (off the Oregon coast) 1993 — Research on the relationship between submarine geomorphology and fluid flow at the central Cascadia accretionary complex

29. Crater Lake, Oregon 1989 — Midwater biological investigations with *Deep Rover* submersible (with National Park Service and Oregon State University)

30. Eel River Basin, Northern California 1997 — MBARI *R/V Point Lobos* cruise to study cold seeps, carbonates, and pressurized gases at depth

31. Cape Mendocino/ Point Arena 1987 — Studies of the jets and eddies of the California current (with the Office of Naval Research)

32. Monterey Bay 1987-1997 — Various collaborations with Long Marine Laboratory of the University of California, Santa Cruz; the Naval Postgraduate School; Hopkins Marine Station of Stanford University; Moss Landing Marine Laboratories

33. Southern California (offshore waters) 1995 — MBARI-engineered acoustic equipment used to track whales (with Cornell University Ornithology Lab)

1995 — MBARI-designed acoustic tracking device tested on elephant seals (with University of California, Santa Cruz)

34. Los Angeles 1997 — Identification of chemical compounds which induce oyster larval settlement (with University of California, Los Angeles)

35. Costa Rica (offshore waters) 1994 —Research on fluid expulsion and structural geology at the Mid-America Trench (with University of California, Santa Cruz, and Lamont-Doherty Geological Observatory)

36. Seamount 6, Eastern Pacific 1995 — MBARI multiple drill-corer used on *Alvin* submersible dives to collect hyaloclastites

37. Galapagos 1995 — Midwater ecology studies using *Johnson-Sea-Link* submersible (with the California Academy of Sciences)

38. Eastern/central Pacific 1993 — Iron-Ex: experiment on iron enrichment and phytoplankton production (with Moss Landing Marine Laboratories and others)

39. Waters south of Galapagos 1995 — Iron Ex II: second large-scale experiment on effects of iron enrichment on phytoplankton production (with Moss Landing Marine Laboratories and others)

40. Paita, Peru 1987-present — Studies of seasonal and inter-annual variability in primary production (with Instituto del Mar de Peru)

41. Callao, Peru 1987-1990 — Studies of seasonal and inter-annual variability in primary production (with Direccion de Hidrografia y Navigacion de la Marina)

Atlantic

42. Greenland 1993 — Field monitoring of coastal ice break-up, biological, chemical, and physical parameters (with University of Copenhagen and National Environmental Research Institute of Denmark)

43. Newfoundland, Canada 1997 — Research using MBARI-designed DNA probes for *Pseudo-nitzschia* and *Alexandrium*

44. Gulf of Maine 1995 — Midwater ecology research using *Johnson-Sea-Link* submersible (with Harbor Branch Oceanographic Institution)

1997 — MBARI-designed acoustic equipment used to track harbor porpoises (with University of Rhode Island, National Marine Fisheries Service, Woods Hole Oceanographic Institution, Texas A&M University, University of California, Santa Cruz, and Cornell University)

45. Woods Hole, Massachusetts 1992-1993 — Feasibility test on DNA-based laboratory tests to track the dispersal of *Alexandrium* in ships' ballast water (with Woods Hole Oceanographic Institution)

46. Connecticut 1997 — MBARI-designed laser-measure technology in use (at Institute of Marine and Coastal Sciences, University of Connecticut at Avery Point)

47. New Brunswick, N.J. 1997 — MBARI-designed laser-measure technology in use (at Institute of Marine and Coastal Sciences, Rutgers University)

48. Goddard Space Center, Maryland 1995 — Preparations for reception of SeaWiFS satellite data on ocean color (with NASA)

49. South Carolina 1996 —Tests and improvements of institute's DNA probes for toxic *Pseudo-nitzschia* and *Alexandrium* (with National Science Foundation and NOAA)

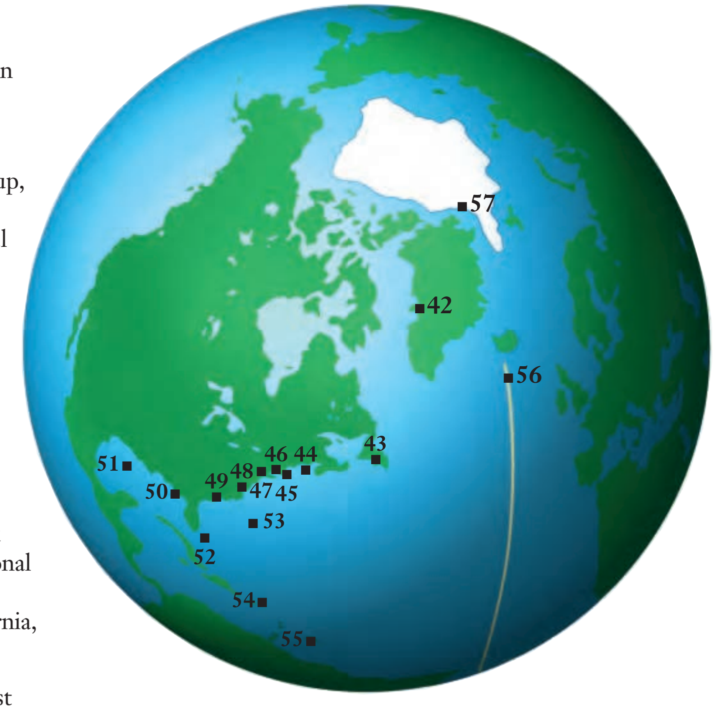
50. Louisiana 1996 — DNA probes used for research on toxic *Pseudo-nitzschia* in the Gulf of Mexico (with Louisiana Universities Marine Consortium)

51. Gulf of Mexico 1996 — Hydrophone array tow used to locate whales (with Texas A&M University)

52. Bahamas 1991 — Midwater ecology investigations using *Johnson-Sea-Link* submersible (with University of California, Los Angeles, and Woods Hole Oceanographic Institution)

53. Bermuda 1994-1997 — Nitrate OsmoAnalyzers deployed on the Bermuda Atlantic Time Series study mooring (with Bermuda Biological Station for Research and University of California, Santa Barbara)

54. U.S. Virgin Islands 1989 — Research on midwater ecology using the *Johnson-Sea-Link* submersible (with University of California, Los Angeles, and Woods Hole Oceanographic Institution)



55. Barbados 1994-1997 — OsmoSampler deployed in an Ocean Drilling Project bore-hole (with Scripps Institution of Oceanography)

56. North Atlantic 1993 — Studies on primary production as related to carbon fluxes (on NOAA Long Line Cruise)

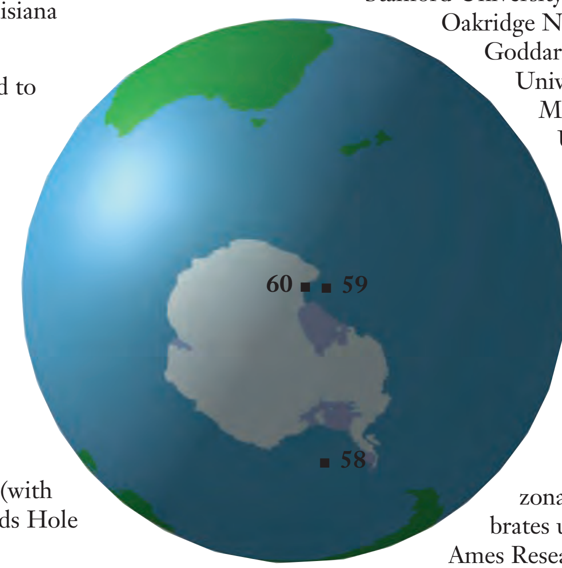
North Pole

57. Arctic Ocean, Fram Strait 1989 — Studies of upper ocean waters (with University of Tennessee and the Office of Naval Research)

Antarctica

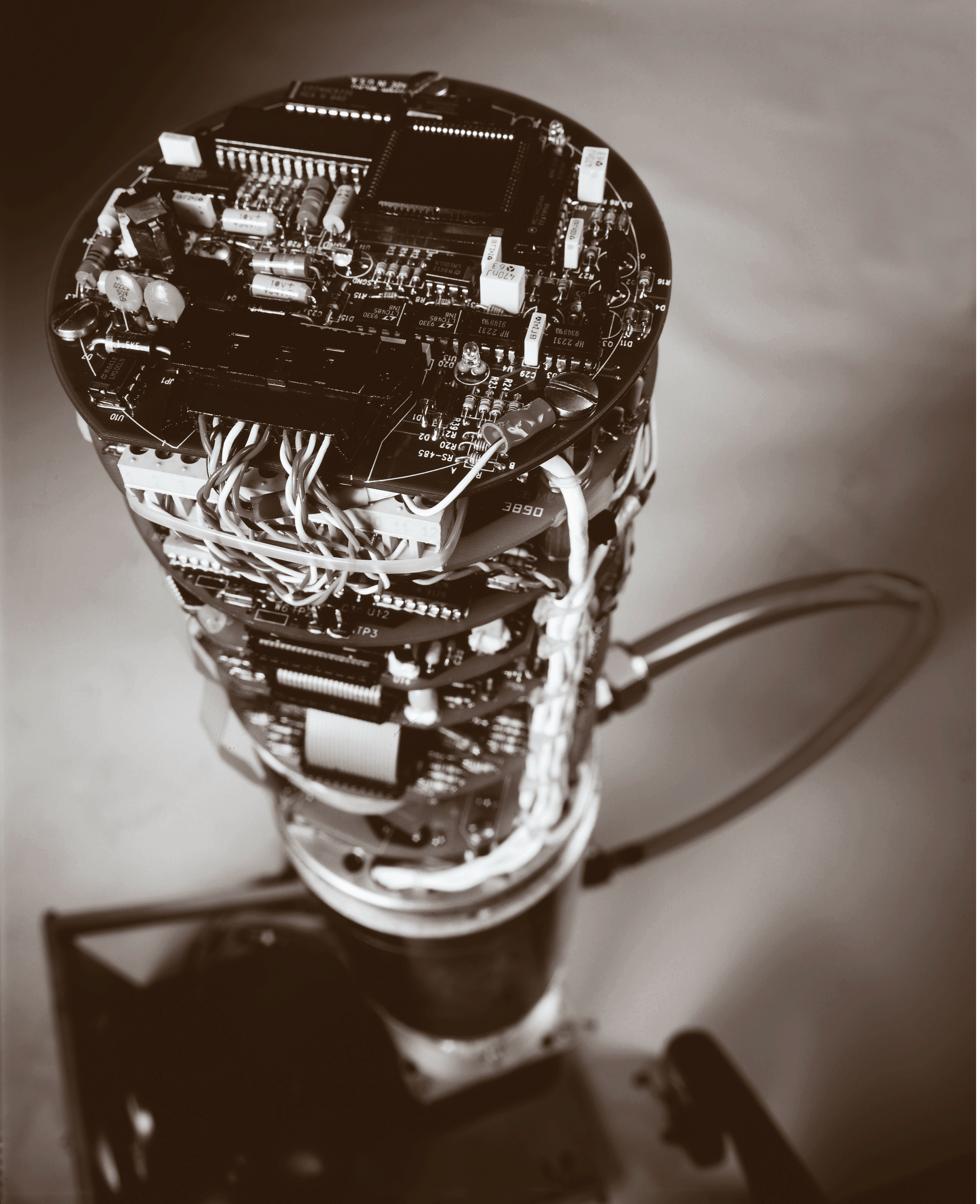
58. Weddell Sea, Antarctica 1992 — Studies of vertical migration of zooplankton using upward-looking acoustic imaging and trawling data (with Scripps Institution of Oceanography)

59. Ross Sea, Antarctica 1996-1997 — Studies of pelagic and benthic processes and communities (with Rice University, Stanford University, University of Tennessee, Oakridge National Laboratories, NASA Goddard Space Center, Colgate University, University of Michigan, Ohio State University, University of Maryland, University of Wisconsin)



60. McMurdo Sound, Antarctica 1991-1994 — Analysis of currents and plume waters from sewage outfall at McMurdo Station (with Montana State University)

1991-1994 Studies of zonation of benthic invertebrates using an ROV (with NASA Ames Research Center)



M. Leet for MBARI

Controller for Tiburon's *thrusters, a collaborative product of MBARI and Moog Corporation.*

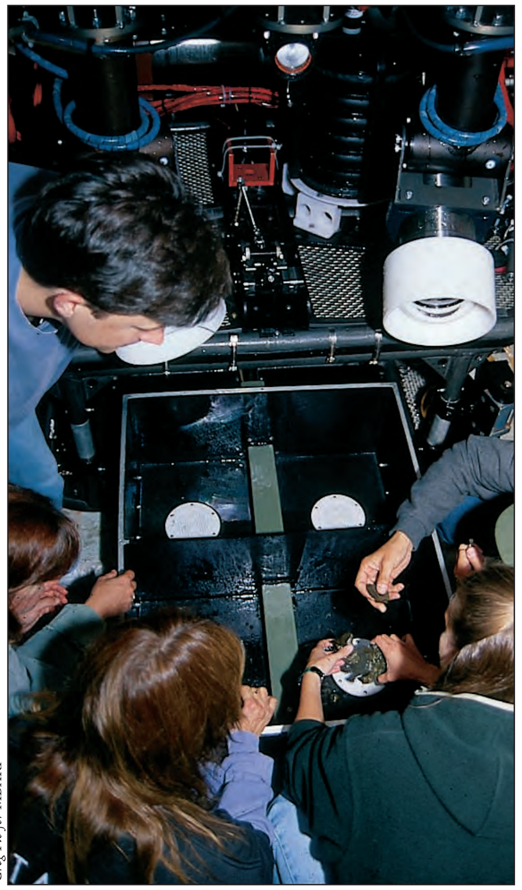
Deeper and Further

The Monterey Bay Aquarium Research Institute embarks on its second decade of operations with a sharpened sense of identity, achieved through years of institution-building. While he lived, founder David Packard provided continual guidance for MBARI's pursuits. In November 1995, four months before his death, he articulated his vision for the institute one last time:

"The mission of MBARI is to achieve and maintain a position as a world center for advanced research and education in ocean science and technology, and to do so through the development of better instruments, systems, and methods for scientific research in the deep waters of the ocean. MBARI emphasizes the peer relationship between engineers and scientists as a basic principle of its operation...All of the activities of MBARI must be characterized by excellence, innovation, and vision."

To carry out this mission the institute has defined six main goals, which reflect MBARI's priorities over the last decade, as well as its future direction. The first goal is to identify important areas of marine science where research progress is limited by the lack of appropriate technology. MBARI will continue to build on its strengths, particularly in the areas of ROV design and operation and development of instruments and systems for long-term, *in situ* oceanographic monitoring. In addition, with input from the institute staff and board of directors, national science agencies, and other consultants, MBARI is drawing up a prioritized list of technology-limited areas in marine science. Reductions in federal support for basic research has resulted in a reluctance on the part of researchers to tackle projects of long duration and high risk. As one of only two privately funded oceanographic research centers in the country, MBARI has a special opportunity and responsibility to undertake such projects.

One example of an area of long-term, technology-limited research recently added to the MBARI agenda is the study of dynamic processes that occur at mid-ocean ridges and submarine volcanoes. Institute scientists are investigating broad questions about linkages between tectonic forces,

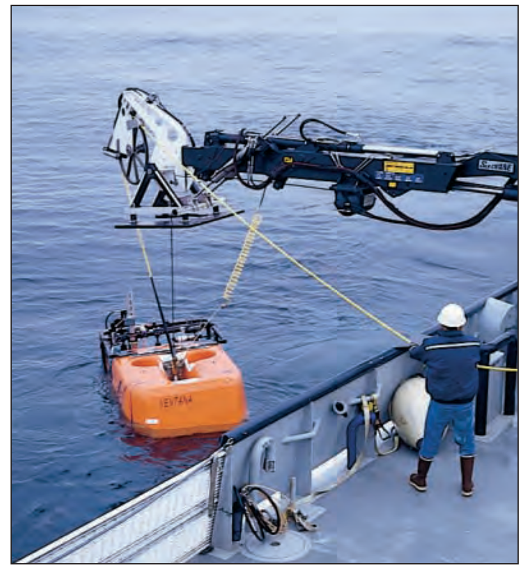


Geology team (clockwise from bottom left) Debra Stakes, Jennifer Reynolds, Mike Begnaud, and Karen Salamy recover the first scientific rock samples collected by Tiburon*, from Carmel Canyon, mid-1997.*

underwater eruptions and subsurface movements of molten rock (magma), the development and effects of hydrothermal vents, and biological populations that inhabit the extreme micro-environments created by these events.

MBARI's second major objective follows from the first: to develop sophisticated systems for investigating the marine environment and its inhabitants where high scientific potential exists. Technology development at the institute will continue to draw on outside expertise and depend on close collaboration between designers and developers with future users and operators of the technical systems. Ocean technology needs already identified, and being pursued or considered for development at MBARI, include:

- upgraded moorings, for use in the Monterey Bay region and beyond, that will be lighter in weight, less costly, more durable, and will include more advanced and integrated instrument controls and satellite data transmission, as well as surface-to-subsurface links
- new instruments, systems, and tools to expand ROV capabilities for specific science missions
- stable, low-power chemical analyzers and samplers for a wide spectrum of chemical compounds
- improved underwater navigation systems for obtaining precise location information critical to biological and geological studies
- advances in ROV video and powerful, versatile databases, both shipboard and onshore, for cataloging video-based information
- "genosensor" technology that will allow rapid, reliable, real-time quantification of a range of toxic phytoplankton and, eventually, bacteria, viruses, and single-celled zooplankton
- more sophisticated techniques for measuring crustal strain at the seafloor
- improved power-supply systems and increased data transmission capabilities for ocean-bottom observatories
- a transportable ROV-system that can be deployed from suitably equipped ships anywhere in the world.



Aaron Gregg assists in launching Ventana *from the* R/V Point Lobos.

Dedication to the evolvement of sophisticated technology positions MBARI at the cutting edge of marine research and development—a road that is not always smooth or without risk. A case in point is the performance of the institute's second ship, the *R/V Western Flyer*, acquired in 1996. Elements of its design, such as the all-aluminum structure, are novel, and the overall SWATH design is uncommon. During one of its first major research expeditions, ship's crew discovered a small number of hairline cracks in the *R/V Western Flyer's* struts, which connect the twin hulls to the main ship structure. This discovery prompted a complete structural analysis of the vessel. The cracks will necessitate repairs and a time delay before the *R/V Western Flyer* can fulfill its purpose and make multi-day research voyages outside Monterey Bay. However, the experience gained from this setback will advance knowledge of SWATH design and performance standards, which will be shared with the oceanographic community.

To achieve its full potential, MBARI must reach beyond the conception and development of leading-edge technology for ocean research. Successfully addressing research problems in the ever-challenging ocean environment requires that the institute also meet the highest possible performance standards for the operation of its equipment and technological systems. This is the institute's third major objective.

The fourth major aim is to conduct high-quality, innovative research that maximizes effective management and use of all MBARI assets, from the creativity and skills of its highly talented staff to its ships, ROVs, and other resources. While this objective flows logically from the previous three, it requires careful planning and the frequent evaluation of science and engineering needs. The institute pursues a defined research agenda that emphasizes long-term, technology-intensive projects of higher risk. At the same time, MBARI will remain open to opportunities of promising scientific merit that arise from unpredicted findings, such as the discoveries of cold seeps in Monterey Bay.

MBARI's commitment to education remains a strong priority. To this end the institute's fifth main objective is to develop, in collaboration with the Monterey Bay Aquarium, innovative programs that maximize the educational value of

M. Lett for MBARI

Greg Pio for MBARI

(top and bottom) The R/V Western Flyer *at sea.*

MBARI's research results. The challenge to find appropriate ways to broaden public knowledge about the oceans will be met by all MBARI staff, whose involvement with cutting-edge research and technology makes them ambassadors for the exciting world of marine science. Utilizing the institute's video library, its real-time environmental data resources, institute Web pages, and Web-based educational projects, MBARI will share its findings with the general public.

The final objective—to transfer research results, technology, and operational techniques to the marine science community worldwide—is integral to the institute's mission and in keeping with its status as a non-profit corporation. MBARI staff will continue to collaborate with the most talented external researchers available in the effort to disseminate findings, breakthroughs in technology, methods, and systems to expand understanding of the ocean environment.

Poised on the threshold of a new millenium, with Marcia McNutt as its president and executive director, MBARI is superbly equipped to earn its place in the vanguard of institutions dedicated to plumbing the ocean's depths and unlocking its secrets. Or, to paraphrase David Packard, to go deeper, stay longer, and take the necessary risks to find answers to the most important questions about the most mysterious realm on our home planet.

Selected Publications

Adams, P. B., J. L. Butler, **C. H. Baxter**, T. E. Laidig, K. A. Halin, and W. W. Wakefield (1995). Population estimates of Pacific coast groundfish from video transects and swept-area trawls. *Fishery Bulletin*, **93**: 446-455.

Abbott, M. R., K. H. Brink, C. R. Booth, D. Blasco, **L. A. Codispoti**, P. P. Niiler, and S. R. Ramp (1990). Observations of phytoplankton and nutrients from a Lagrangian drifter off northern California. *Journal of Geophysical Research*, **95**: 9393-9409.

Anbar, A. D., Y. L. Yung, and **F. P. Chavez** (1996). Methyl bromide: Ocean sources, ocean sinks, and climate sensitivity. *Global Biogeochemical Cycles*, **10**: 175-190.

Austin, Jr., J. A., C. S. Fulthorpe, G. S. Mountain, **D. L. Orange**, and M. E. Field (1996). Continental-margin seismic stratigraphy: Assessing the preservation potential of heterogeneous geological processes operating on continental shelves and slopes. *Oceanography*, **9**: 173-178.

Baggeroer, A. B., B. Sperry, **K. Lashkari**, C.-S. Chiu, J. H. Miller, P. N. Mikhalevsky, and K. von der Heydt (1994). Vertical array receptions of the Heard Island transmissions. *Journal of the Acoustical Society of America*, **96**: 2395-2413.

Barber, R. T. and **F. P. Chavez** (1991). Regulation of primary productivity rate in the equatorial Pacific Ocean. *Limnology and Oceanography*, **36**: 1803-1815.

Barber, R. T., M. P. Sanderson, S. T. Lindley, F. Chai, **J. Newton**, C. C. Trees, D. G. Foley, and **F. P. Chavez** (1996). Primary productivity and its regulation in the equatorial Pacific during and following the 1991-92 El Niño. *Deep-Sea Research II*, **43**: 933-970.

Barry, J. P. and Dayton, P. K. (1991). Physical heterogeneity and the community organization of marine systems. In: *Ecological Heterogeneity*, edited by J. Kolasa and S. T. A. Pickett. Springer-Verlag, New York, New York, pp. 268-320.

Barry, J. P. and **C. H. Baxter** (1993). Survey design considerations for deep-sea benthic communities using ROVs. *Marine Technology Society Journal*, **26**: 20-26.

Barry, J. P., **C. H. Baxter**, R. D. Sagarin, and S. E. Gilman (1995). Climate-related, long-term faunal changes in a California rocky intertidal community. *Science*, **267**: 672-675.

Barry, J. P., **H. G. Greene**, **D. L. Orange**, **C. H. Baxter**, **B. H. Robison**, **R. E. Kochevar**, J. W. Nybakken, D. L. Reed, and C. M. McHugh (1996). Biologic and geologic characteristics of cold seeps in Monterey Bay, California. *Deep-Sea Research I*, **43**: 1739-1762.

Barry, J. P., M. M. Yoklavich, G. M. Cailliet, D. A. Ambrose, and B. S. Antrim (1996). Trophic ecology of the dominant fishes in Elkhorn Slough, California. *Estuaries*, **19**: 115-138.

Barry, J. P., **R. E. Kochevar**, and **C. H. Baxter** (1997). The influence of pore-water chemistry and physiology in the distribution of vesicomyid clams at cold seeps in Monterey Bay: Implications for patterns of chemosynthetic community organization. *Limnology and Oceanography*, **42**: 318-328.

Barry, J. P. and **R. E. Kochevar** (In press). *Calyptogena diagonalis*, a new vesicomyid bivalve from subduction zone seeps in the eastern North Pacific. *Veliger*.

Barry, J. P., **R. E. Kochevar**, **C. H. Baxter**, and C. Harrold (In press). *Calyptogena packardana*, a new species of vesicomyid bivalve from cold seeps in Monterey Bay, California. *Veliger*.

Bates, T. S., R. P. Kiene, G. V. Wolfe, P. A. Matrai, **F. P. Chavez**, **K. R. Buck**, B. W. Blomquist, and R. W. Cuhel (1994). The cycling of sulfur in surface seawater of the Northeast Pacific. *Journal of Geophysical Research*, **99**: 7835-7843.

Beier, J. A., S. Wakeham, **C. H. Pilskaln**, and S. Honjo (1991). Enrichment in saturated compounds of Black Sea interfacial sediment. *Nature*, **351**: 642-644.

Berelson, W. M., J. McManus, K. H. Coale, **K. S. Johnson**, T. Kilgore, D. Burdidge, and C. H. Pilskaln (1996). Biogenic matter diagenesis on the sea floor: A comparison between two continental margin transects. *Journal of Marine Research*, **54**: 731-762.

Synthesis Panel, Effects Panel, Mitigation Panel (**P. G. Brewer**), Adaptation Panel, and E. A. P. P. Committee on Science (1992). In: *Policy implications of greenhouse warming—mitigation, adaptation, and the science base.* National Academy Press, Washington, D. C., 918 pages.

Brewer, P. G., D. M. Glover, C. Goyet, and D. K. Shafer (1995). pH of the North Atlantic Ocean: Improvements to the global model for sound absorption in sea water. *Journal of Geophysical Research*, **100**: 8761-8776.

Brewer, P. G. (1997). Ocean chemistry of the fossil fuel CO_2 signal: The haline signal of "business as usual." *Geophysical Research Letters*, **24**: 1367-1369.

Brewer, P. G. (Chair), Panel on boundary layer dynamics, Naval Studies Board (1997). *Boundary Layer Dynamics*, National Academy Press, 40 pages.

Brewer, P. G., C. Goyet, and **G. E. Friederich** (1997). Direct observation of the oceanic CO_2 increased revisited. *Proceedings of the National Academy of Sciences, USA*, **94**: 8308-8313.

Brewer, P. G., F. M. Orr, Jr., **G. E. Friederich**, K. A. Kvenvolden, and **D. L. Orange** (1997). Hydrate formation during controlled release of CH_4 and CO_2 in Monterey Bay. *American Chemical Society, Division of Fuel Chemistry*, **42**: 475-479.

Brewer, P. G., F. M. Orr, Jr., **G. E. Friederich**, K. A. Kvenvolden, **D. L. Orange**, **J. McFarlane**, and **W. Kirkwood** (1997). Deep-ocean field test of methane hydrate formation from a remotely operated vehicle. *Geology*, **25**: 407-410.

Brewer, P. G. (In press). Chemical Oceanography. In: *Introduction to Earth Systems: Processes and Issues*, edited by G. Ernst. Cambridge University Press.

Brezinski, M. A., D. R. Phillips, **F. P. Chavez**, and **G. E. Friederich** (In press). Silica production in the Monterey California upwelling system. *Limnology and Oceanography*.

Broenkow, W. W., **M. A. Yuen**, and M. A. Yarbrough (1992). VERTEX: Biological implications of total attenuation and chlorophyll and phycoerythrin fluorescence distributions along a 2000 m deep section in the Gulf of Alaska. *Deep-Sea Research*, **39**: 417-437.

Brown, K. M. and **D. L. Orange** (1993). Structural aspects of diapiric mélange emplacement: The Duck Creek diapir. *Journal of Structural Geology*, **15**: 831-847.

Buck, K. R., H. J. Marchant, H. A. Thomsen, and D. L. Garrison (1990). *Kakoeca antarctica* gen et sp. nov., a loricate choanoflagellate (Acanthoecidae, Choanoflagellida) from Antarctic sea ice with a unique protoplast suspensory membrane. *Zoologica Scripta*, **19**: 389-394.

Buck, K. R., **F. P. Chavez**, and H. A. Thomsen (1991). Choanoflagellates of the central California waters: Abundance and distribution. *Ophelia*, **33**: 179-186.

Buck, K. R., G. Ærtebjerg, J. Larsen, and H. Thomsen (1992). Biomass and abundance of pelagic cyanobacteria and protists from the transition area between the Baltic Sea and the North Sea, July 1990. In: *Proceedings of the 12th Baltic Marine Biologists Symposium*, edited by E. Bjørnestad, L. Hagerman, and K. Jensen. Olsen & Olsen, Fredensborg, Denmark, pp. 35-42.

Buck, K. R., P. A. Bolt, W. N. Bentham, and D. L. Garrison (1992). A dinoflagellate cyst from Antarctic sea ice. *Journal of Phycology*, **28**: 15-18.

Buck, K. R., D. L. Garrison, and T. L. Hopkins (1992). Abundance and distribution of tintinnid ciliates in an ice edge zone during the austral autumn. *Antarctic Science*, **4**: 3-8.

Buck, K. R., L. Uttal-Cooke, **C. H. Pilskaln**, D. L. Roelke, M. C. Villac, G. A. Fryxell, L. Cifuentes, and **F. P. Chavez** (1992). Autoecology of the diatom *Pseudo-nitzschia australis*, a domoic acid producer, from Monterey Bay, California. *Marine Ecology Progress Series*, **84**: 293-302.

Buck, K. R. and **F. P. Chavez** (1994). Diatom aggregates from the open ocean. *Journal of Plankton Research*, **16**: 1449-1457.

Buck, K. R. and **J. Newton** (1995). Fecal pellet flux in Dabob Bay during a diatom bloom: Contribution of microzooplankton. *Limnology and Oceanography*, **40**: 306-315.

Buck, K. R., **F. P. Chavez**, and L. Campbell (1996). Basin-wide distributions of living carbon components and the inverted trophic pyramid of the central gyre of the North Atlantic Ocean, summer 1993. *Aquatic Microbial Ecology*, **10**: 283-298.

Cangelosi, G. A., A. M. Hamlin, **R. Marin III**, and **C. A. Scholin** (In press). Detection of stable pre-rRNA in toxigenic *Pseudo-nitzschia* species. *Applied and Environmental Microbiology*.

Chapin, T. P., **K. S. Johnson**, and K. H. Coale (1991). Rapid determination of manganese in sea water by flow-injection analysis with chemiluminescence detection. *Analytica Chimica Acta*, **249**: 469-478.

Chavez, F. P. (1989). Size distribution of phytoplankton in the central and eastern tropical Pacific. *Global Biogeochemical Cycles*, **3**: 27-35.

Chavez, F. P., **R. T. Barber**, and M. P. Sanderson (1989). The potential primary production of the Peruvian upwelling ecosystem. In: *Instituto del Mar del Peru (IMARPE)*, edited by H. S. D. Pauly, P. Muck, and J. Mendo. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), GmbH, Eschborn, Federal Republic of Germany; and International Center for Living Aquatic Resources Management (IFCLARM), Manila, Philippines, Callao, Perú, pp. 50-63.

Chavez, F. P., **K. R. Buck**, and **R. T. Barber** (1990). Phytoplankton taxa in relation to primary production in the equatorial Pacific. *Deep-Sea Research*, **37**: 1733-1752.

Chavez, F. P., **R. T. Barber**, P. M. Kosro, A. Huyer, S. R. Ramp, T. Stanton, and B. Rojas de Mendiola (1991). Horizontal advection and the distribution of nutrients in the coastal transition zone off northern California: Effects on primary production, phytoplankton biomass, and species composition. *Journal of Geophysical Research*, **96**: 14833-14848.

Chavez, F. P. and R. C. Brusca (1991). The Galapagos Islands and their relation to oceanographic processes in the tropical Pacific. In: *Galapagos Marine Invertebrates*, edited by M. J. James. Plenum Press, New York, New York, pp. 9-33.

Chavez, F. P., **K. R. Buck**, K. H. Coale, J. H. Martin, G. R. DiTullio, N. A. Welschmeyer, A. C. Jacobson, and **R. T. Barber** (1991). Growth rates, grazing, sinking and iron limitation of equatorial Pacific phytoplankton. *Limnology and Oceanography*, **36**: 1816-1827.

Chavez, F. P. (1995). A comparison of ship and satellite chlorophyll from California and Peru. *Journal of Geophysical Research*, **100**: 24855-24862.

Chavez, F. P., **K. R. Buck**, R. R. Bidigare, D. M. Karl, D. Hebel, M. Latasa, L. Campbell, and **J. Newton** (1995). On the chlorophyll *a* retention properties of glass-fiber GF/F filters. *Limnology and Oceanography*, **40**: 428-433.

Chavez, F. P. and S. S. Smith (1995). Biological and chemical consequences of open ocean upwelling systems. In: *Upwelling in the Ocean: Modern Processes and Ancient Records*, edited by C. P. Summerhayes, K. C. Emeis, M. V. Angel, R. L. Smith, and B. Zeitzschel. J. Wiley & Sons, Chichester, England, pp.149-169.

Chavez, F. P. and J. R. Toggweiller, (1995). Physical estimates of global new production: The upwelling contribution. In: *Upwelling in the Ocean: Modern Processes and Ancient Records*, edited by C. P. Summerhayes, K. C. Emeis, M. V. Angel, R. L. Smith, and B. Zeitzschel. John Wiley and Sons Ltd., Chichester, England, pp. 312-320.

Chavez, F. P. (1996). Forcing and biological impact of onset of the 1992 El Niño in central California. *Geophysical Research Letters*, **23**: 265-268.

Chavez, F. P., **K. R. Buck**, **S. K. Service**, **J. Newton**, and R. T. Barber (1996). Phytoplankton variability in the central and eastern tropical Pacific. *Deep-Sea Research II*, **43**: 835-870.

Chavez, F. P., **S. K. Service**, and S. Buttrey (1996). Temperature-nitrate relationships in the central and eastern tropical Pacific. *Journal of Geophysical Research*, **101**: 20553-20564.

Chavez, F.P., **J. T. Pennington**, **R. Herlien**, **H. W. Jannasch**, **G. Thurmond**, and **G. E. Friederich** (1997). Moorings and drifters for real-time interdisciplinary oceanography. *American Meteorological Society*, **14**: 1199-1211.

Chin, C. S., **K. S. Johnson**, and K. H. Coale (1992). Spectrophotometric determination of dissolved manganese in natural waters with 1-(2Pyridylazo)-2-naphthol: Application to analysis *in situ* in hydrothermal plumes. *Marine Chemistry*, **37**: 65-82.

Chin, C. S., K. H. Coale, V. Elrod, **K. S. Johnson**, G. Massoth, and E. Baker (1994). *In situ* observations of dissolved iron and manganese in hydrothermal vent plumes, Juan de Fuca Ridge. *Journal of Geophysical Research*, **99**: 4969-4984.

Clague, D. A. (1996). The growth and subsidence of the Hawaiian-Emperor volcanic chain. In: *The Origin and Evolution of Pacific Island Biotas, New Guinea to Eastern Polynesia: Patterns and Processes*, edited by A. Keast and S. E. Miller. SPB Academic Publishing, The Netherlands, pp. 35-50.

Coale, K. H., C. S. Chin, G. J. Massoth, **K. S. Johnson**, and E. T. Baker (1991). *In situ* chemical mapping of dissolved iron and manganese in hydrothermal plumes. *Nature*, **352**: 325-328.

Coale, K. H., **K. S. Johnson**, P. M. Stout, and **C. M. Sakamoto** (1992). Determination of copper in sea water using a flow-injection method with chemiluminescence detection. *Analytica Chimica Acta*, **266**: 345-351.

Coale, K. H., S. E. Fitzwater, R. M. Gordon, **K. S. Johnson**, and R. T. Barber (1996). Control of community growth and export production by upwelled iron in the equatorial Pacific Ocean. *Nature*, **379**: 621-624.

Coale, K. H., **K. S. Johnson**, S. E. Fitzwater, R. M. Gordon, S. Tanner, **F. P. Chavez**, **L. Ferioli**, **C. M. Sakamoto**, **P. Rogers**, F. Millero, P. Steinberg, P. Nightingale, D. Cooper, W. Cochlan, M. Landry, J. Constantinou, G. Rollwagen, A. Transvina, and **R. M. Kudela** (1996). A massive phytoplankton bloom induced by an ecosystem-scale iron fertilization experiment in the equatorial Pacific Ocean. *Nature*, **383**: 495-501.

Coble, P. G., L. A. Gagosian, **L. A. Codispoti**, **G. E. Friederich**, and J. P. Christensen (1991). Vertical distribution of dissolved and particulate fluorescence in the Black Sea. *Deep-Sea Research*, **38**: 985-1001.

Codispoti, L. A., **G. E. Friederich**, T. T. Packard, and **R. T. Barber** (1988). Remotely driven thermocline oscillations and dentrification in the eastern south Pacific: The potential for high dentrification rates during weak coastal upwelling. *The Science of the Total Environment*, **75**: 301-318.

Codispoti, L. A. (1989). Phosphorus vs. nitrogen limitation of new and export production. In: *Productivity of the Ocean: Present and Past*, edited by W. H. Berger, V. S. Smetacek, and G. Wefer. John Wiley & Sons, Ltd., Somerset, England, pp. 377-394.

Codispoti, L. A., **R. T. Barber**, and **G. E. Friederich** (1989). Do nitrogen transformations in the poleward undercurrent off Peru and Chile have a globally significant influence? In: *Poleward Flows Along Eastern Ocean Boundaries*, edited by M. J. Bowman, R. T. Barber, C. N. K. Mooers, and J.A. Raven. Springer-Verlag, New York, New York, pp. 281-310.

Codispoti, L. A., D. Clark, T. Packard, and J. J. Walsh (1990). Global change and the cycling of biogenic materials in the Arctic Ocean and its adjacent seas. In: *Arctic System Science*, *Ocean-Atmosphere-Ice Interactions*, edited by R. Moritz, K. Aagaard, D. J. Baker, L. A. Codispoti, J. L. Smith, W. D. Smith, R. C. Tipper, and J. E. Walsh. Joint Oceanographic Institutions, Inc., Washington, D. C., pp. 51-73.

Codispoti, L. A., **G. E. Friederich**, J. W. Murray, and **C. M. Sakamoto** (1991). Chemical variability in the Black Sea: Implications of continuous vertical profiles that penetrated the oxic/anoxic interface. *Deep-Sea Research*, **38**: 691-710.

Codispoti, L. A., **G. E. Friederich**, **C. M. Sakamoto**, and L. I. Gordon (1991). Nutrient cycling and primary productivity in the marine systems of the Arctic and Antarctic. *Journal of Marine Systems*, **2**: 359-384.

Codispoti, L. A., J. W. Elkins, T. Yoshinari, **G. E. Friederich**, **C. M. Sakamoto**, and T. T. Packard (1992). On the nitrous oxide flux from productive regions that contain low oxygen waters. In: *Oceanography of the Indian Ocean*, edited by B. N. Desai. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, India, pp. 271-284.

Cook, T. L. and **D. S. Stakes** (1995). Biogeological mineralization in deep-sea hydrothermal deposits. *Science*, **267**: 1975-1979.

Crane, L. N. and **K. Lashkari** (1996). Sound production of gray whales, *Eschrichtius robustus*, along their migration: A new approach to signal analysis. *Journal of the Acoustical Society of America*, **100**: 1878-1886.

Davis, D. L. and **C. H. Pilskaln** (1993). Measurements with underwater video: Camera field width calibration and structured light. *Marine Technology Society Journal*, **26**: 13-19.

Denner, W. W., **K. Lashkari**, J. H. Miller, and C.-S. Chiu (1992). Possible uses of submarine canyons in acoustic thermometry. *Journal of the Acoustical Society of America*, **92**: 2350.

Dickey, T. D., D. Frye, **H. W. Jannasch**, E. Boyle, and A. H. Knap (1997). Bermuda sensor system testbed: First accessible, regularly serviced, deep-ocean mooring with satellite and ship-shore communications to test interdisciplinary sensors—hurricane proven. *Sea Technology*, **38**: 81-86.

Dickey, T. D., D. Frye, **H. W. Jannasch**, E. Boyle, D. Manov, D. Sigurdson, J. McNiel, M. Stramska, A. Michaels, N. Nelson, D. Siegel, G. Chang, J. Wu, and A. Knap (In press). Preliminary results from the Bermuda Testbed Mooring Program. *Deep-Sea Research*.

Dickey, T. D., D. Frye, J. McNiel, D. Manov, N. Nelson, D. Sigurdson, **H. W. Jannasch**, D. Siegel, A. Michaels, and R. Johnson (In press). Upper ocean temperature response to Hurricane Felix as measured by the Bermuda testbed mooring. *Marine Weather Review*.

Dixon, J. E., **D. A. Clague**, R. Poreda, and P. Wallace (In press). Volatiles in alkalic basalts from the North Arch Volcanic Field, Hawaii: Extensive degassing of deep submarine-erupted alkalic series lavas. *Journal of Petrology*.

Dugdale, R. C., F. P. Wilkerson, R. T. Barber, and **F. P. Chavez** (1992). Estimating new production in the equatorial Pacific Ocean at 150° W. *Journal of Geophysical Research*, **97**: 681-686.

Dugdale, R. C., F. Wilkerson, D. Halpern, **F. P. Chavez**, and R. T. Barber (1994). Remote sensing of seasonal and annual variation of equatorial new production: A model for global estimates. *Advances in Space Research*, 169-178.

Elrod, V. A., **K. S. Johnson**, and K. H. Coale (1991). Determination of subnanomolar levels of iron (II) and total dissolved iron in seawater by flow injection analysis with chemiluminescence detection. *Analytical Chemistry*, **63**: 893-898.

Eppley, R. W., **F. P. Chavez**, and R. T. Barber (1992). Standing stocks of particulate carbon and nitrogen in the equatorial Pacific at 150° W. *Journal of Geophysical Research*, **97**: 655-661.

Feely, R. A., R. Wanninkhof, C. E. Cosca, M. J. McPhaden, R. H. Bryne, F. J. Millero, **F. P. Chavez**, T. Clayton, D. M. Campbell, and P. P. Murphy (1994). The effect of tropical instability waves on CO_2 distributions along the equator in the Easter equatorial Pacific during the 1992 ENSO event. *Geophysical Research Letters*, **21**: 277-280.

Fiedler, P. C., V. Philbrick, and **F. P. Chavez** (1991). Oceanic upwelling and productivity in the eastern tropical Pacific. *Limnology and Oceanography*, **36**: 1834-1850.

Fiedler, P. C., **F. P. Chavez**, D. W. Behringer, and S. B. Reilly (1992). Physical and biological effects of Los Niños in the eastern tropical Pacific. *Deep-Sea Research*, **39**: 199-219.

Fitzwater, S. E., K. H. Coale, R. M. Gordon, **K. S. Johnson**, and M. E. Ondrusek (1996). Iron deficiency and phytoplankton growth in the equatorial Pacific. *Deep-Sea Research II*, **43**: 995-1015.

Frey, F. A., **D. S. Stakes**, S. R. Hart, N. Walker, and R. Neilsen (1993). Geochemical characteristics of basaltic glasses from the AMAR and FAMOUS axial valleys, Mid-Atlantic ridge (36-37° N.): Petrogenetic implications. *Earth and Planetary Science Letters*, **115**: 117-136.

Friederich, G. E., **C. M. Sakamoto**, **J. T. Pennington**, and **F. P. Chavez** (1994). On the direction of the air-sea flux of CO_2 in the coastal upwelling systems. In: *Global Fluxes of Carbon and its Related Substances in the Coastal Sea-Ocean-Atmosphere System*, edited by S. Tsunogai. Science and Technology Agency, Hokkaido University, Sapporo Hokkaido, Japan, pp. 438-445.

Friederich, G. E., **P. G. Brewer**, **R. Herlein**, and **F. P. Chavez** (1995). Measurement of sea surface partial pressure of CO_2 from a moored buoy. *Deep-Sea Research I*, **42**: 1175-1186.

Garrison, D. L. and **K. R. Buck** (1991). Surface-layer sea ice assemblages in Antarctic pack ice during the austral spring: Environmental conditions, primary production and community structure. *Marine Ecology Progress Series*, **75**: 161-172.

Garrison, D. L., **K. R. Buck**, and M. M. Gowing (1991). Plankton assemblages in the ice edge zone of the Weddell Sea during the austral winter. *Journal of Marine Sciences*, **2**: 123-130.

Garrison, D. L., **K. R. Buck**, and M. M. Gowing (1993). Winter plankton assemblage in the ice edge zone of the Weddel and Scotia Seas: Composition, biomass and spatial distributions. *Deep-Sea Research I*, **40**: 311-338.

Gordon, R. M., K. H. Coale, and **K. S. Johnson** (1997). Iron distributions in the equatorial Pacific: Implications for new production. *Limnology and Oceanography*, **42**: 419-431.

Gordon, R. M., **K. S. Johnson**, and K. H. Coale (In press). Behavior of iron and other trace elements in IronEx I and PlumEx. *Deep-Sea Research*.

Goyet, C., D. R. Walt, and **P. G. Brewer** (1992). Development of a fiber optic sensor for measurement of pCO_2 in sea water: Design criteria and sea trials. *Deep-Sea Research*, **39**: 1015-1026.

Goyet, C. and **P. G. Brewer** (1993). Biochemical properties of the oceanic carbon cycle. In: *Modelling Oceanic Climate Interactions*, edited by J. Willebrand and D. L. T. Anderson. NATO ASI Series. Springer-Verlag, Berlin, Germany, **1**: pp. 271-297.

Goyet, C., **D. L. Davis,** E. T. Peltzer, and **P. G. Brewer** (1995). Development of improved space sampling strategies for ocean chemical properties: Total carbon dioxide and dissolved nitrate. *Geophysical Research Letters*, **22**: 945-948.

Goyet, C. and **D. L. Davis** (1997). Estimation of total CO_2 concentration throughout the water column. *Deep-Sea Research I*, **44**: 859-877.

Grebmeier, J. M. and **J. P. Barry** (1991). The influence of oceanographic processes on pelagic-benthic coupling in polar regions: A benthic perspective. *Journal of Marine Systems*, **2**: 495-518.

Greene, H. G., **D. S. Stakes**, **D. L. Orange**, **J. P. Barry**, and **B. H. Robison** (1993). Application of a remotely operated vehicle in geologic mapping of Monterey Bay, California, USA. In: *Diving for Science, 1993*, edited by J. N. Heine and N. L. Crane. Proceedings of the American Academy of Underwater Sciences, Nahant, Massachusetts, pp. 67-81.

Grimm, K. A. and **D. L. Orange** (1997). Syn-sedimentary fracturing, fluid migration and subaqueous mass wasting: Intrastratal microfractured zones in laminated diatomaceous sediments, Miocene Monterey Formation, California, USA. *Journal of Sedimentary Research*, **67**: 601-613.

Gritton, B. R. and **C. H. Baxter** (1993). Video database systems in the marine sciences. *Marine Technology Society Journal*, **26**: 59-72.

Hamner, W. M., **G. I. Matsumoto**, M. Ghiselin, N. Holland, V. Holland, J. Pearse, and V. Pearse (1991). *The Living Invertebrates: The Ctenophores*. Office of Instructional Development, University of California at Los Angeles. 16 mm film (also available on videotape), 16 minutes.

Hamner, W. M. and **B. H. Robison** (1992). *In situ* observations of giant appendicularians in Monterey Bay. *Deep-Sea Research*, **39**: 1299-1313.

Hanson, A. K., **C. M. Sakamoto-Arnold**, D. L. Huizenga, and D. R. Kester (1988). Copper complexation in Sargasso Sea and gulf stream warm-core ring waters. *Marine Chemistry*, **23**: 181-203.

Hayward, T. L., S. L. Cummings, D. R. Cayan, **F. P. Chavez**, R. J. Lynn, A. W. Mantyla, P. P. Niiler, F. B. Schwing, R. R. Veit, and E. L. Venrick (1996). The state of the California Current in 1995-96: Continuing declines in macrozooplankton biomass during a period of nearly normal circulation. *CalCOFI Reports*, **37**: 22-37.

Herbert, T. D., W. B. Curry, J. A. Barron, **L. A. Codispoti**, R. S. Keir, R. Gersonde, A. C. Mix, B. Mycke, H. Schrader, R. Stein, and H. R. Thierstein (1989). Group report: Geological reconstructions of marine productivity. In: *Productivity of the Ocean: Present and Past*, edited by W. Berger, V. Smetacek, and G. Wefer. John Wiley & Sons, Ltd., pp. 409-428.

Hover, F. S. (1994). Inversion of a distributed system for open-loop trajectory following. *International Journal of Control*, **60**: 671-686.

Hover, F. S., M. A. Grosenbaugh, and M. S. Triantafyllou (1994). Calculation of dynamic motions and tensions in towed underwater cables. *IEEE, Journal of Oceanic Engineering*, **19**: 449-457.

Hover, F. S. (1997). Simulation of stiff massless tethers. *IEEE, Journal of Oceanic Engineering*, **24**: 765-783.

Howington, J. P., G. A. McFeters, **J. P. Barry,** and J. J. Smith (1992). Mapping the McMurdo Station sewage plume. *Marine Pollution Bulletin*, **25**: 9-12.

Huyer, A., P. M. Kosro, J. Fleischbein, S. R. Ramp, T. Stanton, L. Washburn, **F. P. Chavez**, T. J. Cowles, S. D. Pierce, and R. L. Smith (1991). Currents and water masses of the coastal transition zone off northern California, June to August 1988. *Journal of Geophysical Research*, **96**: 14809-14831.

Jannasch, H. W., **K. S. Johnson**, and **C. M. Sakamoto** (1994). Submersible osmotically pumped colorimetric analyzers for the continuous determination of nitrate *in situ*. *Analytical Chemistry*, **66**: 3352-3361.

Jannasch, H. W., B. D. Honeyman, and J. W. Murray (1996). Marine scavenging: The relative importance of mass transfer and reaction rates. *Limnology and Oceanography*, **41**: 82-88.

Johnson, K. S., J. J. Childress, R. R. Hessler, **C. M. Sakamoto-Arnold**, and C. L. Beehler (1988). Chemical and biological interactions in the Rose Garden hydrothermal vent field, Galapagos spreading center. *Deep-Sea Research*, **35**: 1723-1744.

Johnson, K. S., P. M. Stout, W. M. Berelson, and **C. M. Sakamoto-Arnold** (1988). Cobalt and copper distributions in the waters of Santa Monica Basin, California. *Nature*, **332**: 527-530.

Johnson, K. S., **C. M. Sakamoto-Arnold**, and C. L. Beehler (1989). Continuous determination of nitrate concentrations *in situ*. *Deep-Sea Research*, **36**: 1407-1413.

Johnson, K. S., W. M. Berelson, K. H. Coale, T. L. Coley, V. A. Elrod, W. R. Fairey, H. D. Iams, T. E. Kilgore, and J. L. Nowicki (1992). Manganese flux from continental margin sediments in a transect through the oxygen minimum. *Science*, **257**: 1242-1245.

Johnson, K. S., K. H. Coale, and **H. W. Jannasch** (1992). Analytical chemistry in oceanography. *Analytical Chemistry*, **64**: 1065-1075.

Johnson, K. S., J. J. Childress, C. L. Beechler, and **C. M. Sakamoto** (1994). Biogeochemical of hydrothermal vent mussel communities: The deep-sea analogue to the intertidal zone. *Deep-Sea Research I*, **41**: 993-1011.

Johnson, K. S., K. H. Coale, V. A. Eldrod, and N. W. Tindale (1994). Iron photochemistry in seawater from the equatorial Pacific. *Marine Chemistry*, **46**: 319-334.

Johnson, K. S. and **H. W. Jannasch** (1994). Analytical chemistry under the sea surface: Monitoring ocean chemistry *in situ*. *Naval Research Reviews*, **3**: 4-11.

Johnson, K. S. and J. F. Bash (1995). The UNOLS fleet. *Marine Technology Society Journal*, **28**: 19-20.

Johnson, K. S., K. H. Coale, W. M. Berelson, and R. M. Gordon (1996). On the formation of the manganese maximum in the oxygen minimum. *Geochimica et Cosmochimica Acta*, **60**: 1291-1299.

Johnson, K. S., R. M. Gordon, and K. H. Coale (1997). What controls dissolved iron in the world's oceans? *Marine Chemistry*, **57**: 137-161.

Johnson, K. S., R. M. Gordon, and K. H. Coale (1997). What controls dissolved iron in the world's oceans: Author's closing comments. *Marine Chemistry*, **57**: 181-186.

Judge, B. S., **C. A. Scholin**, and D. M. Anderson (1993). RFLP analysis of a fragment of the large-subunit ribosomal RNA gene of globally distributed populations of the toxic dinoflagellate *Alexandrium*. *Biological Bulletin*, **185**: 329-330.

Kahn, L. M., E. A. Silver, **D. L. Orange**, **R. E. Kochevar**, and B. McAdoo (1996). Surficial evidence of fluid expulsion from the Costa Rica accretionary prism. *Geophysical Research Letters*, **23**: 887-890.

Kaufmann, R. S., K. L. Smith, Jr., R. J. Baldwin, R. C. Glatts, **B. H. Robison**, and **K. R. Reisenbichler** (1995). Epipelagic communities in the northwestern Weddell Sea: Results from acoustic, trawl, and trapping surveys. *Antarctic Journal of the United States*, **28**: 138-141.

Kaufmann, R. S., K. L. Smith, Jr., R. J. Baldwin, R. C. Glatts, **B. H. Robison**, and **K. R. Reisenbichler** (1995). The effects of seasonal pack ice on the distribution of macrozooplankton and micronekton in the northwestern Weddell Sea. *Marine Biology*, **124**: 387-397.

Khattak, M. U. K. and **D. S. Stakes** (1993). A metamorphic study of the Nanga Parbat—Haramosh Massif, and the adjoining Ladakh island arc terrane, Northern Pakistan. *Geological Bulletin*, **26**: 1-16.

Kochevar, R. E., N. S. Govind, and J. J. Childress (1993). Identification and characterization of two carbonic anhydrases from the hydrothermal vent tubeworm *Riftia pachyptila* Jones. *Molecular Marine Biology and Biotechnology*, **2**: 10-19.

Kolber, Z. S., R. T. Barber, K. H. Coale, S. E. Fitzwater, R. M. Greene, **K. S. Johnson**, S. Lindley, and P. G. Falkowski (1994). Iron limitation of phytoplankton photosynthesis in the equatorial Pacific Ocean. *Nature*, **371**: 145-148.

Korsmeyer, K. E., **H. Dewar**, N. C. Lai, and J. B. Graham (1996). The aerobic capacity of tunas: Adaptation for multiple metabolic demands. *Comparative Biochemistry and Physiology*, **113**: 17-24.

Korsmeyer, K. E., **H. Dewar**, N. C. Lai, and J. B. Graham (1996). Tuna aerobic swimming performance: Physiological and environmental limits based on oxygen supply and demand. *Comparative Biochemistry and Physiology*, **113**: 45-56.

Kosro, P. M., A. Huyer, S. R. Ramp, R. L. Smith, **F. P. Chavez**, T. J. Cowles, M. R. Abbott, P. T. Strub, **R. T. Barber**, P. Jessen, and L. F. Small (1991). The structure of the transition zone between coastal waters and the open ocean off northern California, Winter and Spring 1987. *Journal of Geophysical Research*, **96**: 14707-14730.

Kudela, R. M. and **F. P. Chavez** (1996). Bio-optical properties in relation to an algal bloom caused by iron enrichment in the equatorial Pacific. *Geophysical Research Letters*, **23**: 3751-3754.

Kudela, R. M. and R. C. Dugdale (1996). Estimation of new production from remotely-sensed data in a coastal upwelling regime. *Advances in Space Research*, **18**: 91-97.

Kudela, R. M. and **F. P. Chavez** (1997). Estimating new production from the quantum yield of nitrate uptake. *SPIE, Ocean Optics XIII*, **2963**: 471-476.

Kudela, R. M., W. P. Cochlan, and R. C. Dugdale (1997). Carbon and nitrogen uptake response to light by phytoplankton during an upwelling event. *Journal of Plankton Research*, **19**: 609-630.

Larson, R. J., **G. I. Matsumoto**, L. P. Madin, and **L. M. Lewis** (1992). Deep-sea benthic and benthopelagic medusae: Recent observations from submersibles and a remotely operated vehicle. *Bulletin of Marine Science*, **51**: 277-286.

Lashkari, K., W. W. Denner, J. Miller, and C.-S. Chiu (1992). Monterey Bay acoustic environmental monitoring system. *Journal of the Acoustical Society of America*, **91**: 2429.

Lashkari, K. and S. Lowder (In press). Ocean acoustic observatory for passive monitoring of the ocean. *Proceedings of the Institute of Acoustics*, Loughborough, England.

Lenarz, W. H., D. VanTresca, W. M. Graham, F. B. Schwing, and **F. P. Chavez** (1995). Explorations of El Niño and associated biological population dynamics off central California. *California Cooperative Oceanic Fisheries Investigations, Report*, **36**: 106-119.

Lipschultz, F., S. C. Wofsy, B. B. Ward, **L. A. Codispoti**, **G. E. Friederich**, and J. W. Elkins (1990). Bacterial transformations of inorganic nitrogen in the oxygen-deficient waters of the Eastern Tropical South Pacific Ocean. *Deep-Sea Research*, **37**: 1513-1541.

Lisin, S. E., E. E. Hannan, **R. E. Kochevar**, C. Harrold, and **J. P. Barry** (1997). Temporal variation in gametogenic cycles of vesicomyid clams. *Invertebrate Reproduction and Development*, **31**: 307-318.

The 1996 Loihi Science Team (**D. A. Clague**) (1997). Rapid response to submarine activity at Loihi Volcano, Hawaii. *EOS, Transactions of the American Geophysical Union*, **78**: 229-233.

Martin, J. H., K. H. Coale, **K. S. Johnson**, S. E. Fitzwater, R. M. Gordon, S. J. Tanner, C. N. Hunter, V. A. Elrod, J. L. Nowicki, T. L. Coley, R. T. Barber, S. Lindley, A. J. Watson, K. Van Scoy, C. S. Law, M. I. Liddicoat, R. Ling, T. Stanton, J. Stockel, C. Collins, A. Anderson, R. Bidigare, M. Ondrusek, M. Latasa, F. J. Millero, K. Lee, W. Yao, J. Z. Zhang, **G. E. Friederich**, **C. M. Sakamoto**, **F. P. Chavez**, **K. R. Buck**, Z. Kolber, R. Greene, P. Falkowski, S. W. Chisholm, F. Hoge, R. Swift, J. Yungel, S. Turner, P. Nightingale, A. Hatton, P. Liss, and N. W. Tindale (1994). Testing the iron hypothesis in ecosystems of the equatorial Pacific Ocean. *Nature*, **371**: 123-129.

Matsumoto, G. I. (1988). A new species of lobate ctenophore, *Leucothea pulchra* sp. nov., from the California Bight. *Journal of Plankton Research*, **10**: 301-311.

Matsumoto, G. I. and W. M. Hamner (1988). Modes of water manipulation by the lobate ctenophore *Leucothea* sp. *Marine Biology*, **97**: 551-558.

Matsumoto, G.I. (1991). Functional morphology and locomotion of the Arctic ctenophore *Mertensia ovum* Fabricius. *Sarsia*, **76**: 177-185.

Matsumoto, G. I. (1991). Swimming movements of ctenophores and the mechanics of propulsion by ctene rows. *Hydrobiologia*, **216/217**: 319-325.

Matsumoto, G. I. and **B. H. Robison** (1992). *Kiyohimea usagi*, a new species of lobate ctenophore from the Monterey submarine canyon. *Bulletin of Marine Science*, **51**: 19-29.

Matsumoto, G. I. and G. R. Harbison (1993). *In situ* observations of foraging, feeding, and escape behavior in three orders of oceanic ctenophores: Lobata, Cestida, and Beroida. *Marine Biology*, **117**: 279-287.

Matsumoto, G. I., **C. H. Baxter**, and E. H. Chen (1997). Observations of the deep-sea trachymedusa *Benthocodon pedunculata*. *Invertebrate Biology*, **116**: 17-25.

Matsumoto, G. I. (In press). *Coeloplana thomsoni* sp. nov., a new benthic ctenophore (Ctenophora: Platyctenida: Coeloplanidae) from Western Australia. *Veliger*.

Matsumoto, G. I. (In press). Phylum Ctenophora. In: *Encyclopedia of Reproduction*, edited by E. Knobil and J. D. Neill. Academic Press, San Diego, California.

McAdoo, B. G., **D. L. Orange**, E. A. Silver, K. McIntosh, L. Abbott, J. Galewsky, L. Kahn, and M. Protti (1996). Seafloor structural observations, Costa Rica accretionary prism. *Geophysical Research Letters*, **23**: 883-886.

Matthews, M. B. and G. S. Moschytz (1994). The identification of nonlinear discrete-time fading-memory systems using neural network models. *IEEE, Transactions on Circuits and Systems II*, **41**: 740-751.

McFeters, G. A., **J. P. Barry**, and J. P. Howington (1993). Distribution of enteric bacteria in Antarctic seawater surrounding a sewage outfall. *Water Research*, **27**: 645-650.

McHatton, S. C., **J. P. Barry**, **H. W. Jannasch,** and D. C. Nelson (1996). High nitrate concentrations in vacuolate, autotrophic marine *Beggiatoa* spp. *Applied and Environmental Microbiology*, **62**: 954-958.

McLain, T. W., S. M. Rock, and **M. J. Lee** (In press). Experiments in the coordinated control of an underwater arm/vehicle system. *Journal of Autonomous Robotics*.

McManus, J., W. M. Berelson, K. H. Coale, **K. S. Johnson**, and T. E. Kilgore (1997). Phosphorous regenerations in continental margin sediments. *Geochimica et Cosmochimica Acta*, **61**: 2891-2907.

McNutt, M. K., D. W. Caress, **J. R. Reynolds**, K. A. Jordahl, and R. A. Duncan (In press). Midplate volcanism in the southern Austral Islands: Problems for plume theory. *Nature*.

Miller, P. E. and **C. A. Scholin** (1996). Identification of cultured *Pseudo-nitzschia* (Bacillariophyceae) using species-specific LSU rRNA-targeted fluorescent probes. *Journal of Phycology*, **32**: 646-655.

Moore, W. S. and **D. S. Stakes** (1994). Data report: Preliminary gamma-ray analyses of samples from Leg 139, edited by M. J. Mottl, E. E. Davis, J. F. Slack, et al. *Proceedings of the Ocean Drilling Program, Scientific Results*, **139**: 737-738.

Murray, J. W., **H. W. Jannasch**, S. Honjo, R. F. Anderson, W. S. Reeburgh, Z. Top, **G. E. Friederich**, **L. A. Codispoti**, and E. Izdar (1989) Unexpected changes in the oxic/anoxic interface in the Black Sea. *Nature*, **338**: 411-413.

Murray, J. W., **L. A. Codispoti**, and **G. E. Friederich** (1995). Oxidation-reduction environments: The suboxic zone in the Black Sea. *Aquatic Chemistry: Interfacial and Interspecies Processes*, edited by C. P. Huang, C. R. O'Melia, and J. J. Morgan. American Chemical Society, Advances in Chemistry Series, **244**: 157-176.

Newman, J. B. (1990). Fiber-optic data network for the ARGO/JASON vehicle system. *IEEE, Journal of Oceanic Engineering*, **15**: 66-71.

Newman, J. B. and **B. H. Robison** (1994). Development of a dedicated ROV for ocean science. *Marine Technology Society Journal*, **26**: 46-53.

Nicole, C. and **K. Lashkari** (1996). Sound production in gray whales along their migration route. *Journal of the Acoustical Society of America*, **100**: 1878-1886.

Nowicki, J. L., **K. S. Johnson**, K. H. Coale, V. A. Eldrod, and S. H. Leiberman (1994). Determination of zinc in seawater using flow injection analysis with fluorometric detection. *Analytical Chemistry*, **66**: 2732-2738.

Nusbaum, R. L., J. D. Green, **D. S. Stakes**, N. Whiting, and M. D. Glascock (1992). The Appling Granite, Georgia, USA: Origin of facies and implications for their evolution. *Southeastern Geology*, **33**: 1-15.

Olivieri, R. A., A. Cohen, and **F. P. Chavez** (1993). An ecosystem model of Monterey Bay. In: *Trophic Models of Aquatic Ecosystems*, edited by V. Christensen and D. Pauly. ICLARM Conference Proceedings, Manila, Philippines, **26**: pp. 315-322.

Orange, D. L., D. Geddes, and J. C. Moore (1993). Structural and fluid evolution of a young accretionary complex: The Hah rock assemblage of the western Olympic Peninsula, Washington. *Geological Society of America Bulletin*, **105**: 1053-1075.

Orange, D. L., R. S. Anderson, and N. A. Breen (1994). Regular canyon spacing in the submarine environment: The link between hydrology and geomorphology. *Geologic Society of America Today*, **4**: 29-39.

Orange, D. L. and M. B. Underwood (1995). Patterns of thermal maturity as diagnostic criteria for interpretation of melange. *Geology*, **23**: 1144-1148.

Orange, D. L. (1996). Long term sub-seafloor observations and investigations. In: *Borehole—A plan to advance post drilling, sub-seafloor science*, edited by B. Carson, K. Becker, G. M. Purdy, R. Wilkens, J. Gieskes, and J. Hildebrand. *Joint Oceanographic Institutions/U.S. Science Advisory Committee*, Washington, D. C., pp. 73-74.

Orange, D. L., E. Knittle, D. Farber, and Q. Williams (1996). Raman spectroscopy of crude oils and hydrocarbon fluid inclusions: A feasibility study. In: *Mineral Spectroscopy: A Tribute to Roger Burns*, edited by M. D. Dyar, C. McCammon, and M. W. Schaefer. The Geochemical Society, Houston, Texas, Special Publication No. **5**: pp. 65-81.

Paduan, J. D. and **L. K. Rosenfeld** (1996). Remotely sensed surface currents in Monterey Bay from shore-based HF radar (CODAR). *Journal of Geophysical Research*, **101**: 20669-20686.

Paytan, A., M. Kastner, and **F. P. Chavez** (1996). Glacial to interglacial fluctuations in productivity in the equatorial Pacific as indicated by marine barite. *Science*, **274**: 1355-1357.

Peltzer, E. T. and **P. G. Brewer** (1993). Some practical aspects of measuring DOC-sampling artifacts and analytical problems with marine samples. *Marine Chemistry*, **41**: 243-252.

Pilskaln, C. H., A. C. Neumann, and J. M. Bane (1989). Periplatform carbonate flux in the northern Bahamas. *Deep-Sea Research*, **36**: 1391-1406.

Pilskaln, C. H. (1991). Biogenic aggregate sedimentation in the Black Sea basin. In: *Black Sea Oceanography*, edited by E. Izdar and J. W. Murray. Kluwer Academic Publishers, Netherlands, pp. 293-306.

Pilskaln, C. H. and T. C. Johnson (1991). Seasonal signals in Lake Malawi sediments. *Limnology and Oceanography*, **36**: 544-557.

Pilskaln, C. H., **J. B. Paduan**, **F. P. Chavez**, R. Y. Anderson, and W. M. Berelson (1996). Carbon export and regeneration in the coastal upwelling system of Monterey Bay, central California. *Journal of Marine Research*, **54**: 1149-1178.

Post, W. M., **F. P. Chavez**, P. J. Mulholland, J. Pastor, T. H. Peng, K. Prentice, and T. Webb III (1992). *Climate Feedbacks in the Global Carbon Cycle*, edited by D. Dunnette and R. O'Brien. Global Environmental Chemistry, American Chemical Society, Washington, D.C., pp. 392-412.

Ramp, S. R., **L. K. Rosenfeld**, T. D. Tisch, and M. R. Hicks (In press). Moored observations of the current and temperature structure over the continental slope off central California. Part I: A basic description of the variability. *Journal of Geophysical Research*.

Reisenbichler, K. R. and T. G. Bailey (1991). Microextraction of total lipid from mesopelagic animals. *Deep-Sea Research*, **38**: 1331-1339.

Reyes, A. O., W. S. Moore, and **D. S. Stakes** (1995). $^{228}Th/^{228}Ra$ ages of a barite-rich chimney from the Endeavour Segment of the Juan de Fuca Ridge. *Earth and Planetary Science Letter*, **131**: 99-113.

Robigou, V., J. R. Delaney, and **D. S. Stakes** (1993). Large massive sulfide deposits in a newly discovered active hydrothermal system, the high-rise hydrothermal vent field: Endeavour Segment, Juan de Fuca Ridge. *Geophysical Research Letters*, **20**: 1887-1890.

Robison, B. H. (1989). Depth of occurrence and partial chemical composition of a giant squid, *Architeuthis*, off southern California. *Veliger*, **32**: 39-42.

Robison, B. H. and K. Wishner (1990). Biological research needs for submersible access to the greatest ocean depths. *Marine Technology Society Journal*, **24**: 34-37.

Robison, B. H. (1992). Bioluminescence in the benthopelagic holothurian *Enypniastes eximia*. *Journal of the Marine Biological Association of the United Kingdom*, **72**: 463-472.

Robison, B. H. (1993). Midwater research methods with MBARI's ROV. *Marine Technology Society Journal*, **26**: 32-39.

Robison, B. H. (1993). New technologies for sanctuary research. *Oceanus*, **36**: 75-80.

Robison, B. H. (1995). Light in the ocean's midwaters. *Scientific American*, **273**: 60-64.

Robison, B. H. (In press). Submersibles in oceanographic research. In: *Proceedings of the Fifth International Congress on the History of Oceanography*.

Robison, B. H., **K. R. Reisenbichler**, **R. E. Sherlock**, **J. M. Bridges**, and **F. P. Chavez** (In press). Seasonal abundance of the siphonophore, *Nanomia bijuga*, in Monterey Bay. *Deep-Sea Research*.

Rosenfeld, L. K., R. L. Molinari, and K. D. Leaman (1989). Observed and modeled annual cycle of transport in the Straits of Florida and east of Abaco Island, The Bahamas (26.5° N). *Journal of Geophysical Research*, **94**: 4867-4878.

Rosenfeld, L. K. (1990). Baroclinic semidiurnal tidal currents over the continental shelf off northern California. *Journal of Geophysical Research*, **95**: 22153-22172.

Rosenfeld, L. K., F. B. Schwing, N. Garfield, and D. E. Tracy (1994). Bifurcated flow from an upwelling center: A cold water source for Monterey Bay. *Continental Shelf Research*, **14**: 931-964.

Rovero, P. J., C. W. Miller, and **K. Lashkari** (1994). A day in the life of a SOSUS array. *Journal of the Acoustical Society of America*, **95**: 2853.

Sakamoto, C. M., **G. E. Friederich**, **S. K. Service**, and **F. P. Chavez** (1996). Development of automated surface seawater nitrate mapping systems for use in open ocean and coastal waters. *Deep-Sea Research I*, **43**: 1763-1775.

Sakamoto, C. M., F. J. Millero, W. Yao, **G. E. Friederich**, and **F. P. Chavez** (In press). Surface seawater distributions of inorganic carbon and nutrients around the Galapagos Islands: Results from the PlumEx experiment using automated chemical mapping. *Deep-Sea Research*.

Scholin, C. A. and D. M. Anderson (1994). Identification of species and strain-specific genetic markers for globally distributed *Alexandrium* (Dinophyceae). I. RFLP analysis of SSU rRNA genes. *Journal of Phycology*, **30**: 744-754.

Scholin, C. A., M. Herzog, M. L. Sogin, and D. M. Anderson (1994). Identification of group and strain-specific genetic markers for globally distributed *Alexandrium* (Dinophyceae). II. Sequence analysis of a fragment of the LSU rRNA gene. *Journal of Phycology*, **30**: 999-1011.

Scholin, C. A., M. C. Villac, **K. R. Buck**, J. M. Krupp, D. A. Powers, G. A. Fryxell, and **F. P. Chavez** (1994). Ribosomal DNA sequences discriminate toxic and nontoxic *Pseudo-nitzschia* species. *Natural Toxins*, **2**: 152-165.

Scholin, C. A., G. M. Hallegraeff, and D. M. Anderson (1995). Molecular evolution of the *Alexandrium tamarense* "species complex" (Dinophyceae): Dispersal in the North American and West Pacific regions. *Phycologia*, **34**: 472-485.

Scholin, C. A. and D. M. Anderson, (1996). Identification of *Alexandrium* species and strains using RFLP analysis of PCR-amplied LSU rDNA. In: *Harmful and Toxic Algal Blooms*, edited by Y. Oshima and Y. Fukuyo. Intergovernmental Oceanographic Commission of UNESCO, Paris, France, pp. 451-454.

Scholin, C. A. and D. M. Anderson (1996). LSU rDNA-based RFLP assays for discriminating species and strains of *Alexandrium* (Dinophyceae). *Journal of Phycology*, **32**: 1022-1035.

Scholin, C. A., **K. R. Buck**, T. Britschgi, G. Cangelois, and **F. P. Chavez** (1996). Identification of *Pseudo-nitzschia australis* (Bacillariophyceae) using rRNA-targeted probes in whole cell and sandwich hybridization formats. *Phycologia*, **35**: 190-197.

Scholin, C. A., **P. E. Miller**, **K. R. Buck**, **F. P. Chavez**, G. Cangelosi, P. Haydock, J. Howard, and P. Harris (1996). DNA probe-based detection of harmful algal species using *Pseudo-nitzschia* species as models. In: *Harmful and Toxic Algal Blooms*, edited by Y. Oshima and Y. Fukuyo. Intergovernmental Oceanographic Commisssion of UNESCO, Paris, France, pp. 439-442.

Scholin, C. A. (In press). Development of nucleic acid probe-based diagnostics for identifying and enumerating harmful algal bloom species. In: *The Physiological Ecology of Harmful Algal Blooms*, edited by D. M. Anderson, G. M. Hallegraeff, and A. D. Cembella. NATO Advanced Study Institute Series. Springer-Verlag, Heidelberg, Germany.

Scholin, C. A. (In press). Morphological, genetic and biogeographic relationships of *Alexandrium tamarense*, *A. catenella* and *A. fundyense*. In: *The Physiological Ecology of Harmful Algal Blooms*, edited by D. M. Anderson, G. M. Hallegraeff, and A. D. Cambella. NATO Advanced Study Institute Series. Springer-Verlag, Heidelberg, Germany.

Scholin, C. A., **P. E. Miller**, **K. R. Buck**, **F. P. Chavez**, P. Harris, P. Haydock, J. Howard, and G. Cangelosi (In press). Detection and quantification of *Pseudo-nitzschia australis* in cultured and natural populations using LSU rRNA-targeted probes. *Limology and Oceanography*.

Smith, W. O., **L. A. Codispoti**, D. M. Nelson, T. Manley, E. J. Buskey, H. J. Niebauer, and G. F. Cota (1991). Importance of *Phaeocystis* blooms in the high-latitude ocean carbon cycle. *Nature*, **352**: 514-516.

Spinrad, R. W., H. Glover, B. B. Ward, **L. A. Codispoti**, and G. Kullenberg (1989). Suspended particle and bacterial maxima in Peruvian coastal waters during a cold water anomaly. *Deep-Sea Research*, **36**: 715-733.

Stakes, D. S., **J. McFarlane**, G. L. Holloway, and H. G. Green (1993). Drilling success from ROV *Ventana*. *EOS*, *Transactions of American Geophysical Union*, 210-211.

Stakes, D. S. and J. M. Franklin (1994). Petrology of igneous rocks at Middle Valley, Juan de Fuca Ridge. *Proceedings of the Ocean Drilling Program*, *Scientific Results*, **139**: 79-102.

Stakes, D. S., G. L. Holloway, **P. Tucker**, **T. C. Dawe**, **D. Burton**, **J. A. R. McFarlane**, and **S. Etchemendy** (In press). Diamond rotary coring from an ROV or submersible for hardrock sample recovery and instrument deployment: The MBARI Multiple-Barrel Rock Coring System. *Marine Technology Society Journal.*

Steinberg, D. K., **M. W. Silver**, **C. H. Pilskaln**, S. L. Coale, and **J. B. Paduan** (1994). Midwater zooplankton communities on pelagic detritus (giant larvacean houses) in Monterey Bay, California. *Limnology and Oceanography*, **39**: 1606-1620.

Steinberg, D. K., **M. W. Silver**, and **C. H. Pilskaln** (1997). Role of mesopelagic zooplankton in the community metabolism of giant larvacean house detritus in Monterey Bay, California, USA. *Marine Ecology Progress Series*, **147**: 167-179.

Stoecker, D. K., **K. R. Buck**, and M. Putt (1992). Changes in the sea-ice brine community during the spring-summer transition, McMurdo Sound, Antarctica, I. Photosynthetic protists. *Marine Ecology Progress Series*, **84**: 265-278.

Stoecker, D. K., **K. R. Buck**, and M. Putt (1993). Changes in the sea-ice brine community during the Spring-Summer transition, McMurdo Sound Antarctica II, Phagotrophic protists. *Marine Ecology Progress Series*, **95**: 103-113.

Stoker, C. R., **J. P. Barry**, D. R. Barch, and B. P. Hine III (1994). Use of telepresence and virtual reality in undersea exploration: 1993 Antarctic telepresence experiment. In: *Technologies in Environmental Applications*, Seattle, Washington, pp. 37-44.

Stoker, C. R., D. R. Barch, B. P. Hine III, and **J. P. Barry** (1995). Antarctic undersea exploration using a robotic submarine with a telepresence user interface. *IEEE, Expert Intelligent Systems & Their Applications*, **10**: 14-23.

Strub, P. T., P. M. Kosro, A. Huyer, and CTZ Collaborators **(F. P. Chavez)** (1991). The nature of the cold filaments in the California current system. *Journal of Geophysical Research*, **96**: 14743-14768.

Syvitski, J. P., C. R. Alexander, M. E. Field, J. V. Gardner, **D. L. Orange**, and **J. W. Yun** (1996). Continental-slope sedimentation: The view from Northern California. *Oceanography*, **9**: 163-167.

Taft, B. A., S. P. Hayes, **G. E. Friederich**, and **L. A. Codispoti** (1991). Flow of Abyssal Water into the Samoa Passage. *Deep-Sea Research*, **38**: Supplement 1, 103-128.

Thomsen, H. A. and **K. R. Buck** (1991). Choanoflagellate diversity. In: *The Biology of Free-Living Heterotrophic Flagellates*, edited by D. J. Patterson and J. Larsen. Clarendon Press, Oxford, England, pp. 259-284.

Thomsen, H. A., **K. R. Buck**, P. A. Bolt, and D. L. Garrison (1991). Fine structure and biology of *Cryothecomonas* gen. nov. (Protista Incertae Sedis) from the ice biota. *Canadian Journal of Zoology*, **69**: 1048-1070.

Thomsen, H. A., **K. R. Buck**, and **F. P. Chavez** (1991). Choanoflagellates of the central California waters: Taxonomy and species assemblages. *Ophelia*, **33**: 131-164.

Thomsen, H. A., **K. R. Buck**, D. Marino, D. Sarno, L. E. Hansen, J. Krupp, and J. B. Ostergaard (1993). *Lennoxia faveolata* gen. et sp. nov. (Diatomophyceae) from South America, California, West Greenland and Denmark. *Phycologia*, **32**: 278-283.

Thomsen, H. A., **K. R. Buck**, and **F. P. Chavez**, (1994). Haptophytes as components of marine phytoplankton. In: *The Haptophyte Algae*, edited by J. C. Green and B. S. C. Leadbetter. Clarendon Press, Oxford, England, Systematics Association, **51**: pp. 187-208.

Tobin, H. J., J. C. Moore, M. E. Mackay, **D. L. Orange**, and L. D. Kulm (1993). Fluid flow along a strike-slip fault at the toe of the Oregon accretionary prism: Implications for the geometry of frontal accretion. *Geological Society of American Bulletin*, **105**: 569-582.

Tusting, R. and **D. L. Davis** (1993). Laser systems and structure: Illumination for quantitative undersea imaging. *Marine Technology Society Journal*, **26**: 5-12.

Uttal, L. and **K. R. Buck** (1996). Dietary study of the midwater polychaete *Poeobius meseres* in Monterey Bay, California. *Marine Biology*, **125**: 333-343.

Vecchione, M., **B. H. Robison**, and C. F. E. Roper (1992). A tale of two species: Tail morphology in paralarval *Chiroteuthis*. *Proceedings of the Biological Society of Washington*, **105**: 683-692.

Villac, M. C., G. A. Fryxell, **F. P. Chavez**, and L. A. Cifuentes (1994). *Pseudo-nitzschia australia* Frenguelli and related species from the west coast of the USA: Occurrence and domoic acid production. *Journal of Shellfish Research*, **12**: 457-465.

Von Langen, P. J., **K. S. Johnson**, K. H. Coale, and V. A. Elrod (In press). Oxidation kinetics of manganese (II) in seawater at nanomolar concentrations. *Geochimica et Cosmochimica Acta*.

Vørs, N., **K. R. Buck**, **F. P. Chavez**, W. Eikrem, L. E. Hensen, J. B. Ostergaard, and H. A. Thomsen (1995). Nanoplankton of the equatorial Pacific with emphasis on the heterotrophic protists. *Deep-Sea Research II*, **42**: 585-602.

Vrieling, E., R. Koeman, **C. A. Scholin**, P. Scheerman, L. Peperzak, M. Veenhuis, and W. Gieskes (1996). Detection of domoic acid-producing *Pseudo-nitzschia* species in the Dutch Wadden Sea by electron microscopy and molecular probes. *European Journal of Phycology*, **31**: 333-340.

Wang, H. H., S. M. Rock, and **M. J. Lee** (1996). OTTER: The design and development of an intelligent underwater robot. *Autonomous Robots*, **3**: 297-320.

Watson, A. J., C. S. Law, D. A. Van Scoy, F. J. Millero, **G. E. Friederich**, M. I. Liddicoat, R. H. Wanninkhof, R. T. Barber, and K. H. Coale (1994). Minimal effect of iron fertilization on sea-surface carbon dioxide concentrations. *Nature*, **371**: 143-145.

Weeks, D. A. and **K. S. Johnson** (1996). Solenoid pumps for flow injection analysis. *Analytical Chemistry*, **68**: 2717-2719.

Widder, E. A., S. A. Bernstein, **D. F. Bracher**, J. F. Case, **K. R. Reisenbichler**, J. J. Torres, and **B. H. Robison** (1989). Bioluminescence in the Monterey submarine canyon: Image analysis of video recordings from a midwater submersible. *Marine Biology*, **100**: 541-551.

Work, T. M., A. M. Beale, L. Fritz, M. A. Quilliam, **M. Silver**, **K. R. Buck**, and J. L. C. Wright, (1993). Domoic acid intoxication of brown pelicans and cormorants in Santa Cruz, California. In: *Toxic Phytoplankton Blooms*, edited by T. J. Smayda and Y. Shimizu. Elsevier Science Publishers B. V., New York, New York, pp. 643-649.

Wright, H. (1990). Design of a multi-media network. *TC Interface*, 10-16.

Yoklavich, M. M., G. M. Cailliet, **J. P. Barry**, D. A. Ambrose, and B. S. Antrim (1991). Temporal and spatial patterns in abundance and diversity of fishes in Elkhorn Slough, California. *Estuaries*, **14**: 465-480.

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