ANNUAL REPORT 2010

MBARI

Monterey Bay Aquarium Research Institute

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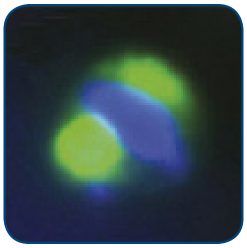

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View From the Masthead

Two thousand ten started with the retooling of our strategic plan and an ambitious set of projects that promised to deliver exciting results and showcase our emphasis on merging science, engineering, and marine operations. What we did not anticipate, however, was working in the Gulf of Mexico! The explosion of the Deepwater Horizon oil platform in late April quickly set us on a new course.

By early May, requests from the U.S. government had drawn MBARI into an enormous effort to assess the fate and transport of oil and gas emanating from the seafloor. Never before had a spill like this occurred at such depth, and never before had a chemical dispersant been applied subsurface at the source in an effort to mitigate the formation of a surface oil slick. How could we help?

Within a week we had reconfigured our upper-water-column autonomous underwater vehicle (AUV) and its automated water sampling system, the gulper, to assist with surveying the areas around the spill site. In collaboration with National Oceanic and Atmospheric Administration (NOAA), our team helped to reveal the presence of a deep, subsurface feature consistent with the hydrocarbon "plume" anticipated from the well failure. Although this was a national disaster of immense consequence, and our response impacted our other operations greatly, it nonetheless served to illustrate MBARI's exceptional operational capability and unfettered ability to respond to changing circumstances.

Our unplanned trip to the Gulf of Mexico was just one of a number of expeditions and field programs that we conducted in 2010. In an ironic counterpart to the work in the Gulf of Mexico, we applied our mapping AUV to survey the SS *Montebello*, a sunken oil tanker. The *Montebello* was torpedoed during World War II and now lies on the seafloor not far from the coast of Cambria, California, with its cargo of crude oil still onboard. Unlike our response in the Gulf of Mexico, the survey of the *Montebello* was planned long in advance to gather information on the disposition of the wreck and on the conditions of the surrounding area. The survey of the *Montebello* illustrates how investments in basic research and development can often return dividends that were not anticipated.

Work to map young faults off the Southern California coast and studies of the Taney Seamounts west of Monterey Bay are also good examples of the year's expeditionary

Engineer Brett Hobson prepares for recovery of the long-range autonomous underwater vehicle *Tethys* at the end of a day's mission during a large October experiment—the first time the vehicle was used for science.

research. In each case, our mapping AUV was used first to produce high-resolution bathymetry for guiding subsequent remotely operated vehicle (ROV) dives for detailed reconnaissance and sample collection. Analysis of the young faults off Southern California revealed recent seafloor deformations—stark reminders of emergent seismic hazards close to home. The Taney Seamounts, in contrast, are an ancient set of submarine volcanoes that have long been inactive. The results of these two expeditions remind us that the Earth's crust is amazingly dynamic and that the ocean seafloor holds many clues about its history and trajectory.

The tandem usage of the mapping AUV and ROV has repeatedly proven to be an effective way to facilitate geological investigations, which often provide rich backdrops for complimentary biological and chemical studies. For example, AUV surveys of the Santa Monica Basin revealed a blister-like feature on the seafloor that was known to eject gas bubbles rich in methane. The site proved ideal for studies sponsored by the National Aeronautics and Space Administration (NASA) astrobiology program, which set forth the challenge of devising tools and techniques for detecting microbial life absent a human presence—as would be needed in the search for life on other planets. In a step toward meeting that objective, we developed and deployed a deep-sea version of the Environmental Sample Processor (D-ESP). The D-ESP utilized its combination of DNA probe technology and chemical sensors around the methane mound to detect microorganisms and the substances on which they thrive.

The expedition to Southern California also provided an opportunity to explore how changes in ocean chemistry resulting from declining oxygen and increased carbon dioxide concentrations can affect the well-being of marine animals. Tests to evaluate this relationship would not be possible without the means to access appropriate ocean environments and the capacity to conduct interdisciplinary experiments that merge ocean chemistry and biology. Conducting work of this kind offers a sobering glimpse of what the future may hold. Similarly, expeditions farther from home provide another perspective on how the ocean is changing. A prime example was a cruise to the Arctic to investigate the discharge of methane from the seafloor.

In parallel with our expeditionary work, Monterey Bay continues to serve as our natural laboratory for the development of new tools and techniques that will be exported to other regions of the world. One highlight of 2010 was the refinement of a sensor for assessing the acidity (pH) of the ocean. Gaining a better understanding of the consequences of the increasing acidity of the open sea requires a chemical sensing network that can be deployed on a global scale. In collaboration with Honeywell and the Applied Physics Laboratory at the University of Washington, we are working to equip a fleet of small, autonomous profiling floats with pH and other chemical sensors.

Long-running time-series studies continue to reveal Monterey Bay to be a very dynamic place. In the surface waters, alterations are apparent in phytoplankton community structure and primary productivity over the past two decades. Shoaling and widening of the oxygen minimum zone is associated with changes in deep-sea communities, too. These alterations are not unique to our local waters and appear to be driven by both natural cycles and human activities. Continued observation of the oceans is critical to further our understanding of these processes and their consequences.

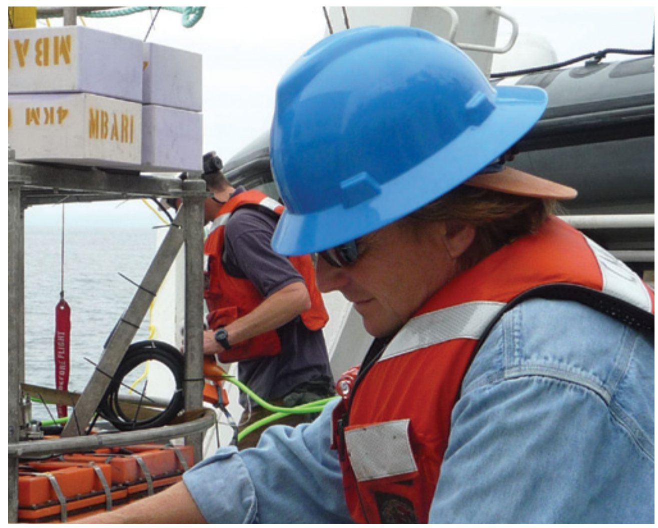
One of the grand challenges in addressing ocean change is connecting the dots between day-to-day ephemeral biological activities and the larger scale, longer lived, and more recognizable large marine ecosystems. A group of MBARI researchers is approaching this problem using our AUV for measuring water properties and autonomous sample acquisition to map and follow various water masses—the same core technologies that were applied during the Gulf of Mexico oil spill response. The ultimate aim of this work is to understand how short-lived biological processes ultimately influence the large-scale exchange of carbon and energy between surface and deep waters.

Each year, MBARI researchers unveil a host of new discoveries. We introduce a new section this year entitled, "Weird and Wonderful" as a tribute to the amazing things we discover, often when we least expect them. Stories chosen to inaugurate this section range from the discovery of a previously unknown lineage of microalgae to a long-brooding octopus that is sure to set a world record!

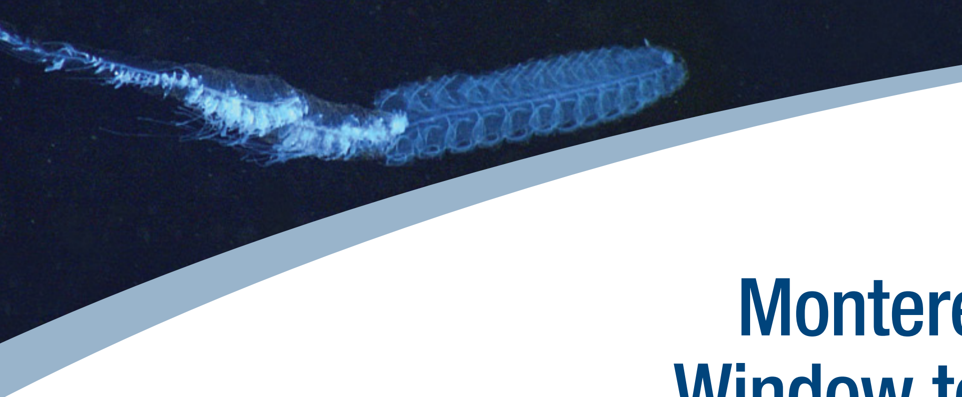
Finally, this year's "Behind the Scenes" focus is on our Division of Marine Operations (DMO). The foregoing synopsis of our work illustrates how critical marine operations are to MBARI's mission. DMO is constantly adjusting ship schedules in response to changing priorities, weather, logistical constraints, and unprecedented opportunities. The flexibility with which they operate, and the can-do attitude they exude, is both essential and inspirational to us all.

The topic of ocean acidification will be a key driver next year and beyond. Working with the Center for Ocean Solutions, we aim to provide a better understanding of what the consequences of ocean acidification will bring by developing new tools, techniques, and experimental procedures. In 2012 MBARI will co-host the Third Symposium on the "Ocean in a High CO_2 World", where the world's experts on the topic will strategize how best to advance understanding of the problem and its implications for policy makers. We will complete our new strategic plan and lay out a technical roadmap for the years ahead. We recognize that the problems we face today are far beyond what we can tackle by ourselves. Fostering alliances and collaborations with other organizations from academia and industry, and ensuring effective communication with the public and policy makers, is essential if we are to take on the grand challenges before us. Two thousand eleven promises to be another year full of discoveries.

Chris Scholin
President and Chief Executive Officer



MBARI President and CEO Chris Scholin helps prepare for the launch of the Deep Environmental Sample Processor aboard the R/V *Western Flyer.*



Monterey Bay as a Window to the World

The Pacific Ocean is the largest and most powerful climate engine on Earth. Monterey Bay, facing west into the Pacific, continues to offer insight into how the greater climate engine runs. MBARI's focused observation and experimentation within Monterey Bay provide detailed data on bay ecosystem and biogeochemical processes. Because many of these processes are also at work across the Pacific and globally, it has become clear that Monterey Bay is truly a window through which the world ocean can be viewed.

Towards a global biogeochemical sensor array

The pH of seawater is a master variable that controls a variety of chemical and physiological processes in the ocean. There is evidence that ocean acidification is occurring globally as a result of the increasing atmospheric carbon dioxide concentration from the burning of fossil fuels. It varies as well due to physical and biological processes. However, there are no simple technologies that allow accurate, precise, and cost-effective monitoring of seawater pH. The development of a simple and highly reliable pH sensor for long-term measurements in the ocean is a major effort of the MBARI Chemical Sensor Laboratory.

This lab group, under the leadership of chemist Ken Johnson, has developed a suite of robust instruments that can be used to detect dissolved chemicals in the ocean. The sensors provide information needed to understand temporal and spatial variability in major biogeochemical processes such as net community production (primary production by algae minus respiration by algae, microbes, and animals at all levels of the food web) and carbon export to the deep sea throughout the world ocean. However, developing a chemical sensor often solves only half of the problem. Making the sensor operate reliably in the marine environment usually involves just as much effort, especially for sensors that are unattended in the open ocean for years at a time. During these long deployments, it is often impossible to directly verify the sensor operation by sampling nearby. One must have high confidence that the signals returned by the sensor are a real measure of change in the ocean, or there is little point in making the deployments. Problems due to biofouling, or hardware or software failures, must be well controlled before the sensors are deployed at sea.

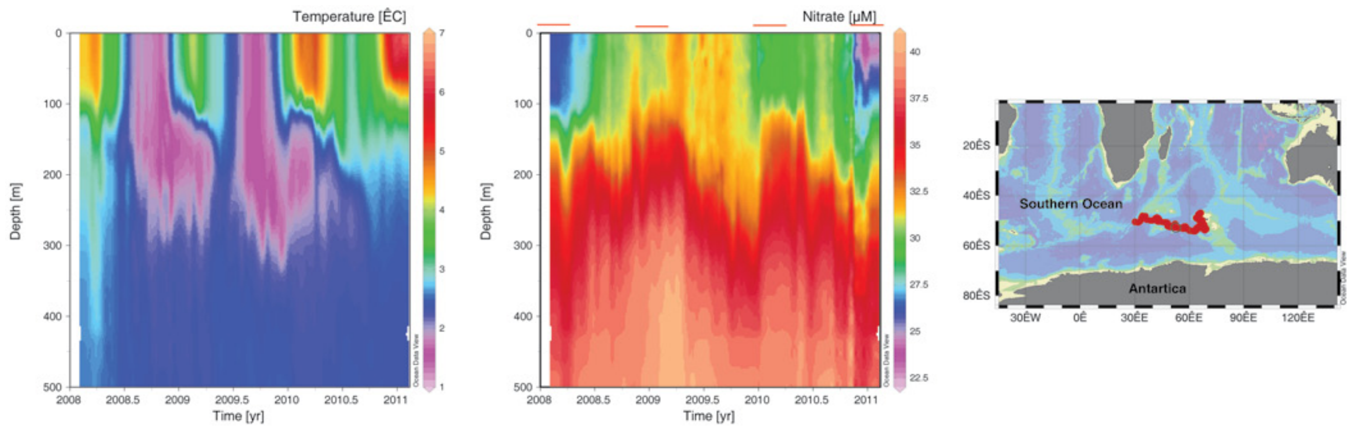


Figure 1: Temperature and nitrate measured in the upper 500 meters over three years using sensors on a profiling float in the Indian Sector of the Southern Ocean. Red bars over the nitrate plot indicate summer drawdown in nitrate due to net community production. Map shows area covered by the float.

To achieve high levels of reliability, the Chemical Sensor group uses a tiered approach to sensor validation. When sensors are developed in the lab, they are first operated for extended periods on the bench, then placed on coastal moorings that transmit data in real time back to land. These moorings are easy to reach within hours if problems are detected. This allows for the rapid diagnosis and solution of sensor failures, and easy sample collection near the moorings to verify that the sensors are reporting accurate data. The Land/Ocean Biogeochemical Observatory (LOBO) mooring array, a set of small moorings conveniently located in Elkhorn Slough and nearshore Monterey Bay, is often used for such testing. Operation of sensors on open-ocean platforms only begin after they prove reliable in the Monterey Bay area.

As an example, the operation of the In Situ Ultraviolet Spectrophotometer (ISUS) nitrate sensor was verified after extended operations in Elkhorn Slough and Monterey Bay. These sensors are now operating on profiling floats throughout the world ocean. Figure 1 shows a three-year nitrate record obtained from a float operating in the Southern Ocean. Each summer, the concentration of nitrate is pulled down to lower values as phytoplankton grow and consume nitrate for the incorporation of nitrogen into key biochemicals such as amino acids. This record of nitrate drawdown tracks the net growth of phytoplankton. Interannual variability in phytoplankton growth, as shown by annual differences in nitrate depletion, is highly correlated with the solar energy input as shown by the variable summer temperature. These observations provide a unique record in a region where there may be no similar measurements. In 2010, a two-year record of nitrate concentration observed from a profiling float near Hawaii and a description of the mechanism by which the phytoplankton obtain nutrients was published by Johnson and his collaborators in the journal *Nature*.

The Chemical Sensor group's work on pH sensors is aimed at gathering data about the acidity of the ocean worldwide. Through a grant from the National Oceanographic Partnership Program, the team is working with the Honey-

Application of Chemical Sensors and National Oceanographic Partnership Program

Project lead/manager: Ken Johnson
Project team: Luke Coletti, Ginger Elrod, Steve Fitzwater, Hans Jannasch, Josh Plant, Carole Sakamoto
Collaborators: Todd Martz, Scripps Institution of Oceanography, La Jolla, California; Joe Needoba, Oregon Health and Science University, Portland; Steve Riser and Dana Swift, University of Washington, Seattle

Chemical Sensor Program

Project lead/manager: Ken Johnson
Project team: Luke Coletti, Ginger Elrod, Steve Fitzwater, Hans Jannasch, Gene Massion, Josh Plant, Carole Sakamoto
Collaborators: Greg Brown, Robert Carlson, and Alex Gu, Honeywell International, Inc.; Todd Martz, Scripps Institution of Oceanography, La Jolla, California; Steve Riser and Dana Swift, University of Washington, Seattle

Figure 2: A LOBO mooring is deployed from the R/V *Zephyr* one kilometer offshore. The mooring carried seven different pH sensor systems for a test of anti-fouling protection schemes during summer and fall 2010.

well Microsensors Process Laboratory to develop pH sensors based on the Honeywell Durafet Ion Sensitive Field Effect Transistor (ISFET)—a pH sensor with exceptional performance. One Durafet unit was deployed in the MBARI seawater test tank for nearly eight months in 2009 with satisfactory sensor output for the entire period. However, fouling organisms settle on sensors deployed in the upper ocean and interfere with data collection. To understand how to control fouling on Durafet sensors, a LOBO mooring with seven different pH sensors was deployed in Monterey Bay (Figure 2). When used on the commercially available LOBO moorings, the Durafet sensor will provide a turnkey system for observing ocean pH.

The experience gained locally with Durafet pH sensors will enable MBARI to deploy the sensors throughout the world ocean for multi-year periods. Work with Honeywell continues toward developing a high-pressure version of the Durafet for deeper multi-year use on profiling floats. These sensors would then enable truly comprehensive observations of ocean acidification and metabolic activity.

Establishing a baseline for the bathypelagic community of Monterey Canyon

The deep pelagic biota is the largest and least known major group of animals on Earth. These animals occupy the largest living space on the planet and represent an incomparable reservoir of global biodiversity (Figure 3). Protecting marine biodiversity in the open sea cannot progress without baseline studies of the animals that inhabit the deep waters. MBARI's bathypelagic study is the first modern step toward that goal.

The publication of the first-ever comprehensive description of a bathypelagic community was a major milestone for scientist Bruce Robison and his Midwater Ecology team. Occupying the ocean between depths of one kilometer and four kilometers, bathypelagic animals had always been studied piecemeal before, with one group of researchers examining the deep-living fishes of one region and another group studying the crustaceans somewhere else. The MBARI study used deep-diving remotely operated vehicles (ROVs) to survey all of the principal animal species that comprise the bathypelagic community of Monterey Canyon. This

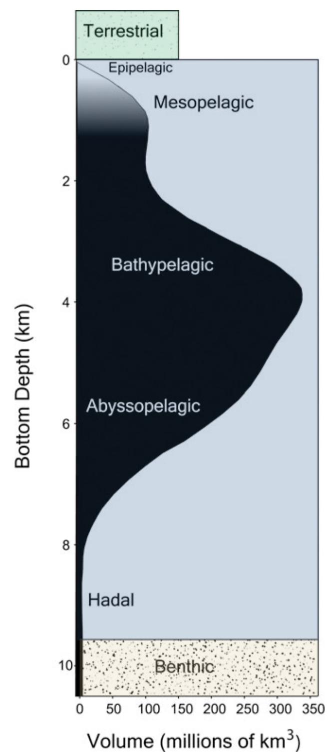


Figure 3: Volume of habitat in the ocean at different depths and on the seafloor (benthic habitat includes one kilometer above the seafloor), with a comparison to the terrestrial habitat (including one kilometer of air above the surface). The bathypelagic includes the water column between one kilometer and four kilometers depth.

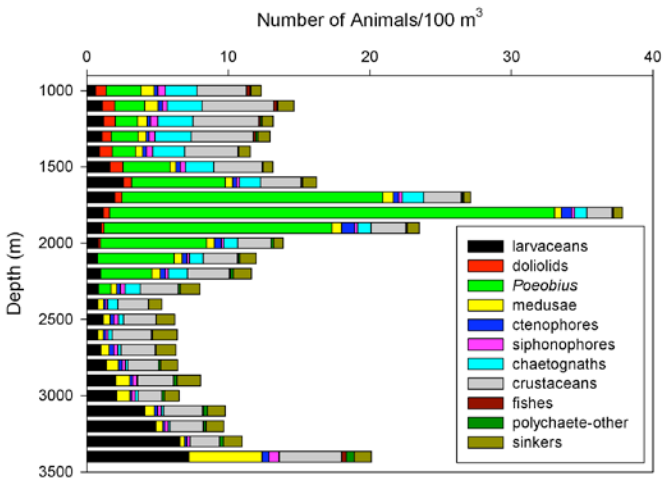


Figure 4: Bathypelagic fauna recorded during oblique video transects over the Monterey Canyon. For this figure animals were categorized into common groups, counted, and pooled within 100-meter-depth increments from 1,000 meters to 3,500 meters. Volume for each transect was calculated using a three-dimensional acoustic flowmeter. Colored bars represent the number of individuals recorded in each faunal group, normalized by the total volume transected within each increment. A total of 15 transects are represented. From Robison et al., 2010.

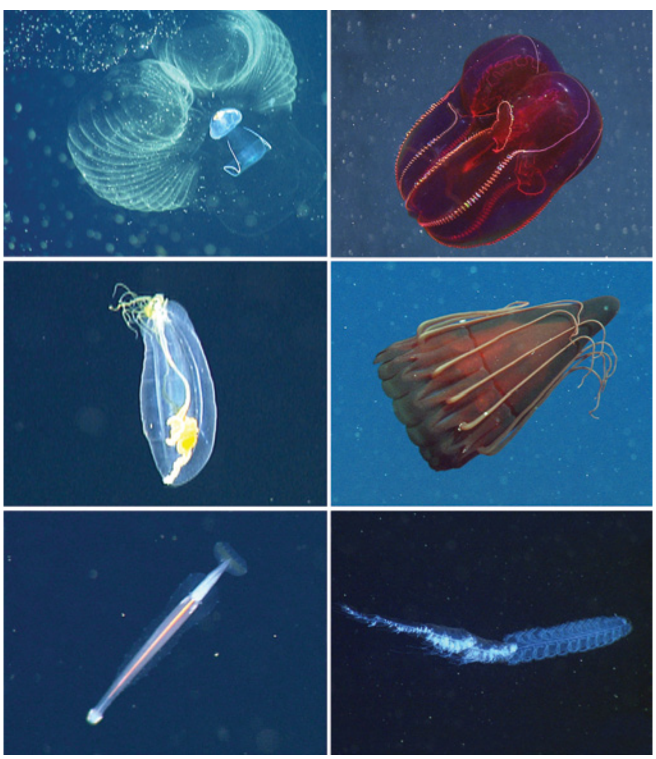


Figure 5: Clockwise from top left, a larvacean (*Bathochordaeus*), a ctenophore (*Lampocteis*), a predatory medusa (*Periphylla*), a siphonophore (*Bargmannia elongata*), a chaetognath (*Eukrohnia fowleri*), and a polychaete worm (*Poeobius*).

publication may become the reference standard against which all such future studies of bathypelagic ecology will be compared.

One reason the MBARI bathypelagic study was successful is that it used ROVs to make the quantitative assessments. In the past such surveys were conducted with nets towed behind ships, a methodology that is highly selective because it grossly underestimates the abundance of soft-bodied gelatinous animals (jellies). While ROVs have their own sampling biases, Robison's team carefully delineated these complications and factored the biases into their overall analysis.

MBARI's detailed examination of bathypelagic community composition and its ecological structure provided several surprises. Unlike the historical picture of bathypelagic ecology, generated from net-tow data, gelatinous animals dominated the fauna throughout the depth range surveyed (Figure 4). The lower levels of the food web, particle feeders, were occupied by larvaceans, doliolids, and the abundant polychaete worm *Poeobius*. The higher levels of the food web consisted largely of predatory medusae, chaetognaths, siphonophores, and ctenophores (Figure 5). Because the gelatinous predators feed on each other, the food web is highly complex and much remains to be determined about

Midwater Ecology

Project lead: Bruce Robison
Project manager: Kim Reisenbichler
Project team: Hendrik Jan Ties Hoving, Rob Sherlock
Collaborators: Stephanie Bush, University of Rhode Island, Kingston; Steven Haddock, George Matsumoto, and Ken Smith, MBARI; Pincelli Hull, Yale University, New Haven, Connecticut; Richard Norris and Karen Osborn, Scripps Institution of Oceanography, La Jolla, California

Midwater Time Series

Project lead: Bruce Robison
Project manager: Rob Sherlock
Project team: Kim Reisenbichler, Kristine Walz
Collaborators: Stephanie Bush, University of Rhode Island, Kingston; Steven Haddock, Kyra Schlining, and Susan von Thun, MBARI; Karen Osborn, Scripps Institution of Oceanography, La Jolla, California; Julia Stewart, Hopkins Marine Station of Stanford University, Pacific Grove, California

the routes and rates of carbon and energy transfer through the system.

Overall, analyses of the ROV video data revealed a rich and diverse fauna that can be separated into upper (1,000 to 2,300 meters depth) and lower (2,400 to 3,300 meters depth) zones, as well as a distinct and populous benthic boundary layer. The distribution of animals correlated with sometimes subtle, sometimes distinct changes in hydrographic data, such as particle density, which were measured by ROV-mounted instruments during the surveys. The all-new methods and procedures used to conduct this study were developed jointly by the science team and members of MBARI's Marine Operations group.

The amount of organic carbon in the bathypelagic food web, which involves gelatinous predators that feed on both soft- and hard-bodied particle feeders, as well as on each other, is substantial but its ecological fate remains uncertain. This is because the true complexity of the food web is still unknown, as very few non-gelatinous jelly-eaters have been identified. One clear conclusion is that there is an enormous biomass of gelatinous animals that occupy these depths; the pattern discerned in Monterey Canyon may be the first step toward answering this global-scale enigma.

A new coastal pelagic ecosystem paradigm?

The Monterey Bay Time Series has documented oceanic fluctuations and trends on seasonal, interannual, and multidecadal timescales using ships, moorings, drifters, autonomous underwater vehicles (AUVs), gliders, satellites, and computer models. As the time series lengthens, its explanatory power increases, and new and sometimes surprising paradigms emerge. This section highlights one of these paradigms elucidated by biological oceanographer Francisco Chavez and his team.

The legendary biological richness of Monterey Bay is due to phytoplankton growth stimulated by coastal upwelling. Centric diatoms are generally considered the signature phytoplankton group within upwelling ecosystems. As described in the 1950s by John Ryther of Woods Hole Oceanographic Institution, centric diatoms are considered the grain crops of the ocean; centric-diatom-dominated coastal upwelling ecosystems produce more fish per unit of primary production than any other ocean ecosystem.

Researchers expected the centric diatoms to increase during the cooler decade of increased nutrient supply that followed the 1997-98 El Niño. This did not happen. Instead two other groups, the pennate diatoms and dinoflagellates, increased dramatically relative to the previous decade (Figure 6). These increases occurred in the late summer and fall, occurring in pulses of several years at a time. Microzooplankton grazers also increased during the cool decade. These organisms are thought to play a controlling role, not in coastal upwelling systems, but in the open ocean where tiny (one to three microns in size) algae dominate, but never truly bloom because nutrients are in short supply (Figure 6C). These algae and the microzooplankton grow at similar rates resulting in a tightly coupled microbial food web. After the strong El Niño researchers found an enhanced population of pennate diatoms during one period (1999-2002) and a dominance of dinoflagellates a few years later (2004-2006). During this period a shallow layer of nutrients combined with thermally stratified Monterey Bay to favor vertically migrating dinoflagellates. Following this "Age of Dinoflagellates"—named after a dinoflagellate-dominated Paleocene (65 to 56 million years ago) warm period with high CO_2 similar to conditions evolving today—the present photosynthetic ecosystem is composed of a combination of centric and pennate diatoms and dinoflagellates.

Monterey Bay is now shared by all three phytoplankton groups with higher biomasses than in the 1990s and a longer and later productive season each summer. These increased biomasses are produced by increased growth and production rates, apparently fueled by increased nutrient flux from the shallow nutrient layer, or nutricline.

Centric diatoms are thought to bloom early in the season because they have the highest growth rates. Later in summer, as upwelling weakens, pennate diatoms are favored; further stratification of nutrients results in dinoflagellate blooms. Curiously, the summer abundance of an important group of phytoplankton predators (the microzooplankton) also increased in the 2000s. In addition to preying on the tiny algae, these organisms graze on centric blooms and may be exerting a top-down control on centric diatoms.

The enhanced biological production during the recent decade can be explained in the following manner. During the first half of the year enhanced nutrient supply drives faster growth rates by centric diatoms whose biomass is regulated by microscopic zooplankton (and possibly larger

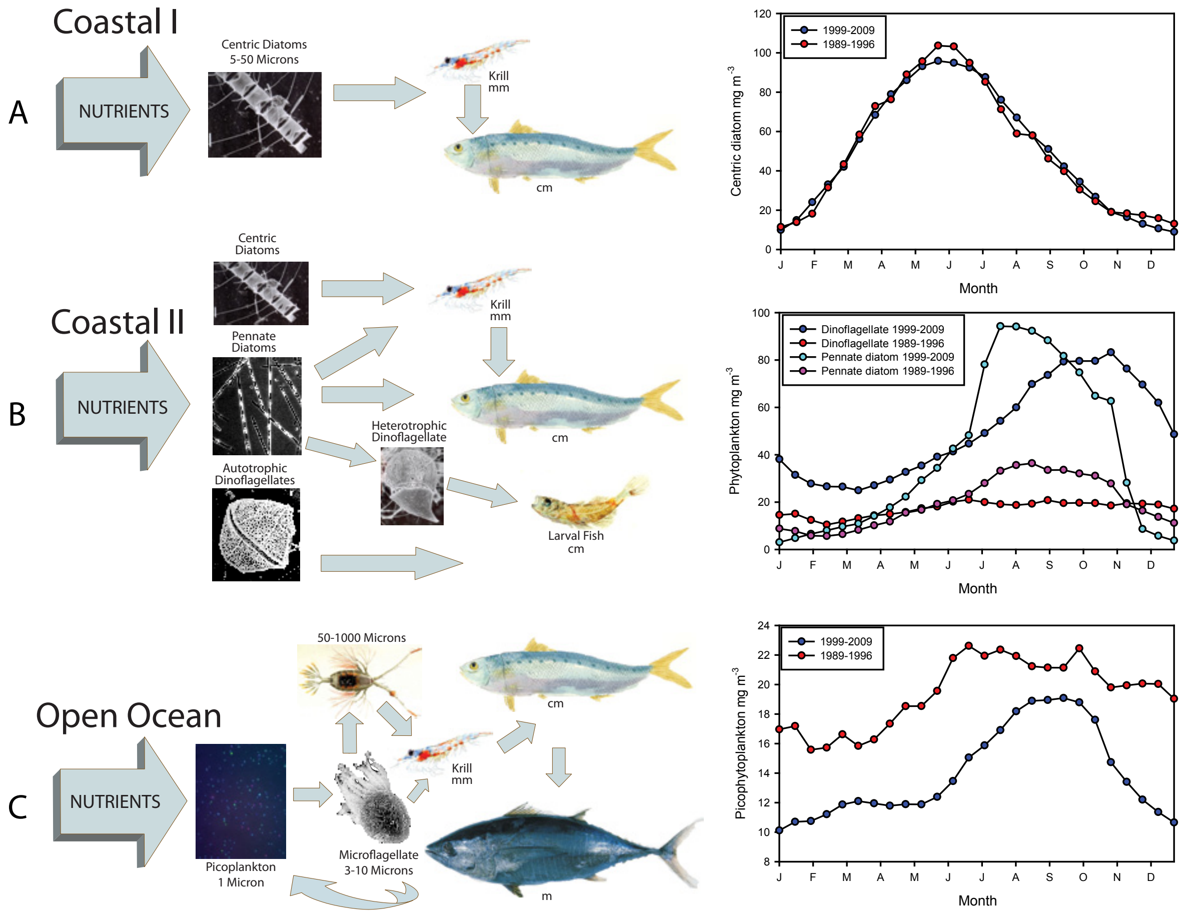


Figure 6: During the 1990s and 2000s, centric diatom blooms in early summer supported krill and sardines (A). Scientists expected that recent and ongoing cooling after the 1997-98 El Niño, along with increases in nutrient supply to the upper ocean, would have further favored centric diatoms. However, their concentrations appeared unchanged relative to the prior warmer decade, but the 2000s saw increased late summer production of dinoflagellates and pennate diatoms. Dinoflagellates likely favor survival of fish larvae (B) and the heterotrophic dinoflagellates that graze on centric diatoms may keep those in check. Monterey Bay has also been less "oceanic" in the 2000s (C), as evidenced by lower concentrations of tiny phytoplankton that dominate less productive offshore ecosystems.

zooplankton such as medusae and chaetognaths) (Figure 6). The increased biological production during the second half of the year is due to increases in the abundance of pennate diatoms and dinoflagellates.

Natural and Human-Induced Change in Monterey Bay and the California Current System

Project lead: Francisco Chavez
Project manager: Tim Pennington
Project team: Luke Beatman, Gernot Friederich, Monique Messié, Reiko Michisaki, Chris Wahl
Collaborator: Marguerite Blum, University of California, Santa Cruz

These shifts have strong ecosystem-wide consequences, some positive, some negative. On the positive side, it has long been known that first-feeding larvae of anchovy or sardine will starve unless they encounter aggregations of dinoflagellate-sized prey. The increases in this prey could lead to greater success in first-feeding larvae and ultimately more abundant fish. On the negative side, if these algae become overwhelmingly dominant, as they were during the Age of the Dinoflagellates (2004-2006), the classic centric-diatom-based food web that supports krill and its predators will collapse. The sharp decline in central California salmon during and following 2004-2006 can probably be attributed to this shift in pelagic ecosystems. Harmful algal blooms—those that affect human, marine mammal, and seabird health—are composed of either pennate diatoms or dinoflagellates. Evolution of this new paradigm emphasizes some fluctuations such as seasons and El Niño, however surprises continue to develop. While we have learned much, much more remains unknown.

Persistent ocean presence reveals ecosystem dynamics

How will a changing climate impact ocean ecosystems? Answering this question requires understanding how marine organisms interact with each other and the environment over time. More importantly, these interactions must be deciphered at the scale of the organisms of interest, whether they are blooms of microscopic plankton or schools of jumbo squid. Traditional methods of repeated, discrete observations often miss important but variable factors that cause ecosystem change. A more effective approach requires a continuous presence at sea following the organisms in their environment. MBARI's Controlled, Agile, and Novel Observing Network (CANON) initiative engages in this approach through the development of new tools and methods for observing spatial and temporal variability in ocean ecosystems. The initiative aims to move from mostly correlative inferences to a process-based view that accurately allows for predictions of how ocean ecosystems will respond to future perturbations.

At the heart of CANON is the use of autonomous mobile platforms integrated with data from fixed moorings, remote sensing, and numerical models to provide an unprecedented view of ecosystem structure and function. Through the use of multiple ocean observing instruments and detailed tracking of the organisms, CANON investigators aim to reveal the dynamics underlying "booms" and "busts" of biological activity in the ocean, without requiring a human presence at sea. Monterey Bay and the contiguous open-ocean waters make for a challenging proving ground for honing this technology.

The CANON team includes scientists from a variety of disciplines, as well as engineers who specialize in autonomy, decision support systems, data management, and adaptive sampling. During 2010, the team collaborated with colleagues at neighboring institutions and found new opportunities for sharing resources to study the coastal and open ocean.

Towards refining science themes and technology requirements

A key element of the CANON strategy is to build a community of researchers who share common interests and needs with the MBARI CANON team. Towards this end, the CANON group hosted a workshop in the spring focused on water sampling, a critical capability for biological process experiments. The workshop was organized around four scientific themes:

- Coastal phytoplankton blooms
- Zooplankton dynamics
- Oxygen minimum zones and ocean acidification
- Open ocean eddies and global primary production

A recurring concern was the need to collect discrete samples to calibrate chemical and biological measurements. These same samples might also foster new discoveries. Another requirement called for a system to intelligently direct usage of the finite number of sampling opportunities. In that regard the MBARI Oceanographic Decision Support System (ODSS) was seen as being essential to integrating disparate types of information collected by various platforms and sensors. This would allow researchers to easily visualize chemical, physical, and biological gradients in real time and remotely determine where and when to collect samples as features of interest evolved.

The workshop provided a clearer view of sampling requirements for future engineering developments and facilitated sharing ODSS and other technologies with the greater community.

Field experiments

The 2010 field experiments emphasized open-ocean ecosystems and coastal phytoplankton blooms. The first involved deployment of a drifting Environmental Sample Processor (ESP) which was then followed for five days. The second experiment concentrated on tracking the development, movement, and decay of coastal phytoplankton blooms.

The open-ocean ESP

In September MBARI's research vessel *Western Flyer* headed westward for 560 kilometers (350 miles) to collect seawater samples. The first part of the cruise was one of discovery—which small plankton were dominating these waters? Comparing the samples with satellite images of sea-surface temperatures allowed researchers to map the fluctuating

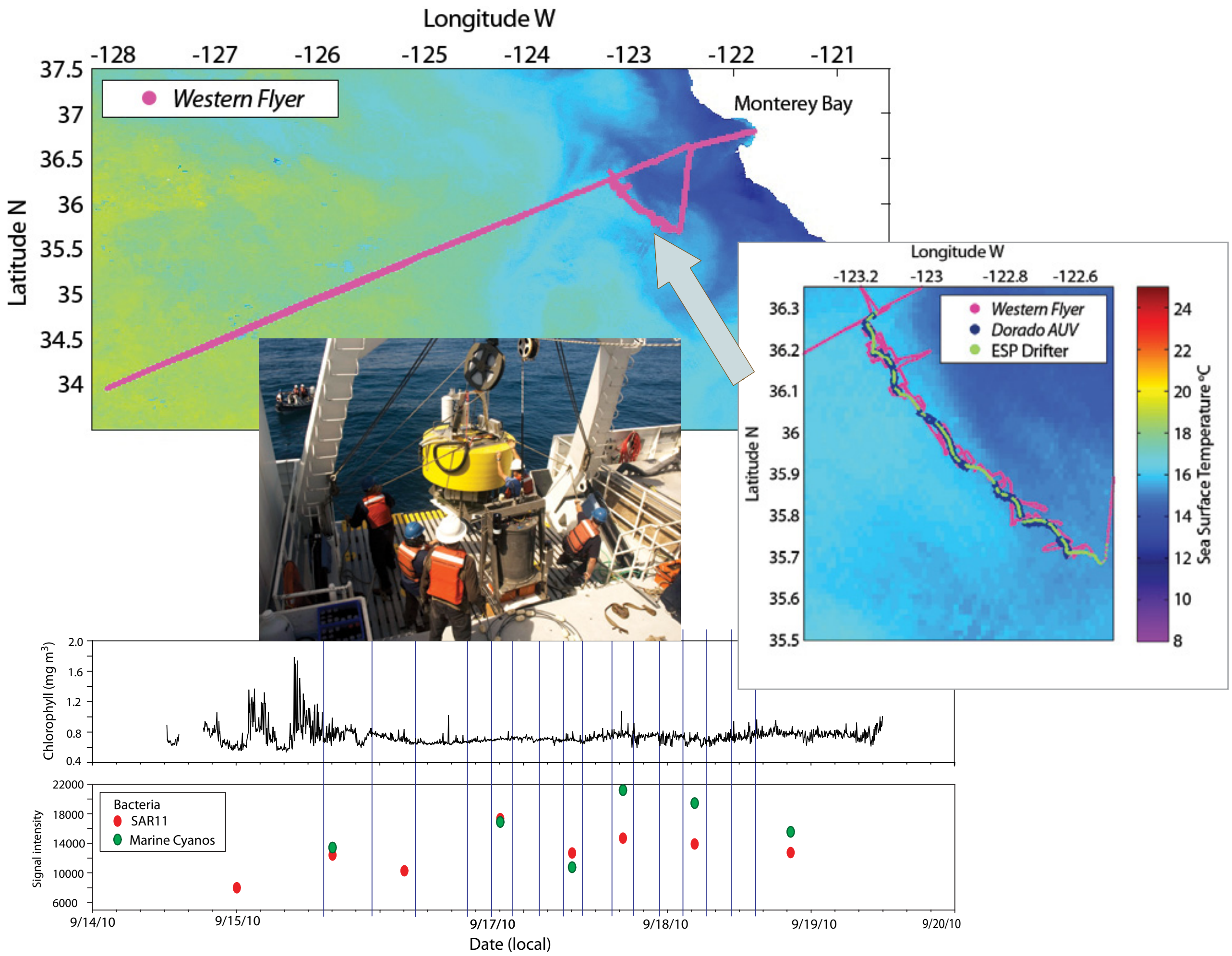


Figure 7: In September the R/V *Western Flyer* used a California Current survey to pick an offshore site (upper panel) for deployment of the ESP drifter (middle left). The *Western Flyer*, the R/V *Zephyr*, and the *Dorado* AUV then conducted experiments and surveys around the ESP while it drifted southeast over the next five days. The effort successfully coordinated multiple platforms around a moving target and produced intensive biological data series in what turned out to be high-nitrate, low-chlorophyll waters. The ESP produced both traditional and genomic data sets (bottom panels).

boundaries of the California Current. Subsequently, the *Western Flyer* transited back toward the California Current's eastern boundary, about 160 kilometers (100 miles) offshore, where it joined the R/V *Zephyr*, which would launch the *Dorado* AUV.

Researchers aboard the *Western Flyer* then deployed a drifting buoy carrying the ESP, a robotic laboratory that collects water samples and analyzes nucleic acids to identify microscopic organisms. In conjunction, researchers aboard the *Zephyr* dispatched MBARI's upper-water-column AUV to circle around the drifting ESP. The objective was to interpret the ESP's automated sample collection and microbial analyses within the context of AUV data on the surrounding chemical, physical, and biological gradients. The group aboard the *Western Flyer* downloaded detailed environmental data in real time and collected water samples for subsequent analyses on shore. (Figure 7)

This experiment involved a number of firsts. Although the ESP had previously been used in stationary, moored configurations, this was the first time it collected data while drifting in a current that directly affects our climate. Programming the AUV to circumnavigate the drifting ESP was a new and complicated task that demonstrated the first significant test of the autonomous control and scheduling system known as the Teleo-Reactive Executive (T-REX).

This multifaceted experiment revealed the complexity of sampling an ever-changing environment. Waters moved in different directions near and just below the surface, and

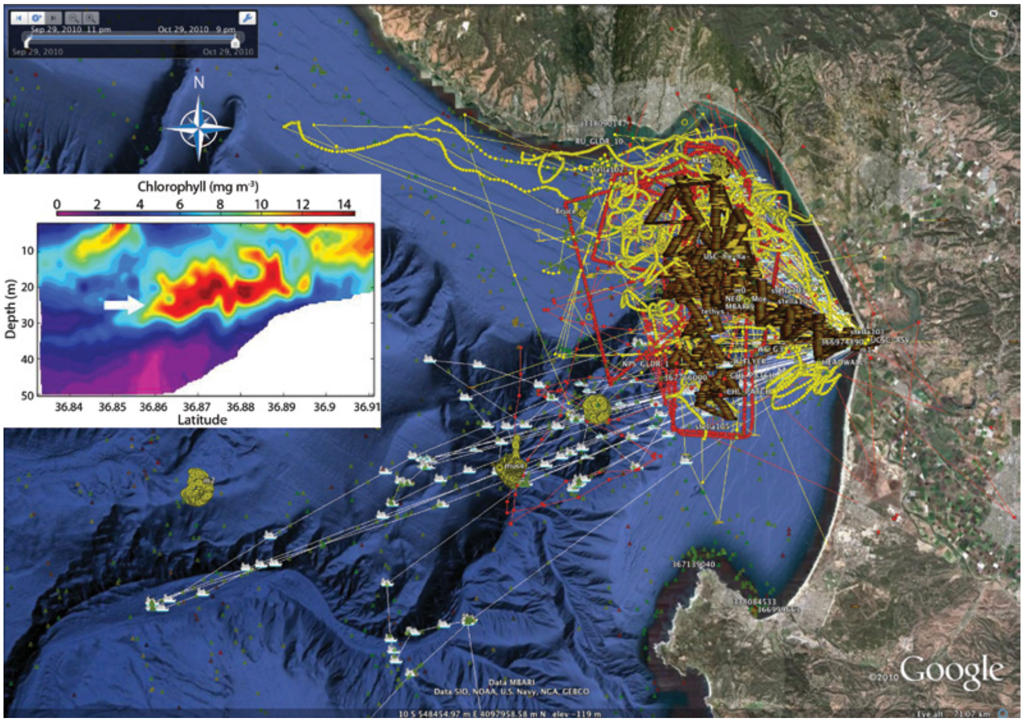


Figure 8: In October the large CANON team worked in Monterey Bay with the goal of intelligently coordinating multiple platforms (main panel) to document a moving feature, in this case a north bay phytoplankton bloom (inset). Over 20 platforms were used (tracks on main panel) including ships, moorings, drifters, AUVs, gliders, aircraft, and satellites. The challenge of effectively deploying this diversity of assets was truly daunting; data synthesis is similarly challenging. The inset shows the two blooms (north, surface dinoflagellates; south, arrow points to subsurface pennate diatoms) tracked during the month long experiment.

varied even more at greater depths. Surprisingly, the photosynthetic community was dominated by picoplankton, tiny organisms that floated in relatively high concentrations of nitrate. The picoplankton appeared to be exploiting ammonia as a nitrogen source—an activity known to occur in iron-limited waters. This phenomenon was known to occur during autumn, however the geographical extent of the affected region—hundreds of square kilometers—surprised the CANON scientists and reminded them that much remains unknown about ocean ecosystems.

Chasing coastal blooms

The October CANON experiment endeavored to determine the role of coastal phytoplankton blooms on the health and functioning of ocean ecosystems. MBARI coordinated the CANON efforts as part of a larger experiment involving over 10 institutions from the government, non-profit, educational, and commercial sectors (Figure 8). MBARI contributed major components of the observing system infrastructure: three ESPs, the *Dorado* AUV, the long-range AUV *Tethys*, three moorings, several drifters, and ship and small-boat operations. The prototype ODSS integrated experiment data for all participants to access and visualize.

The monthlong experiment aimed to identify, characterize, and predict the development and movement of these blooms on timescales of days to weeks. Focusing on northern Monterey Bay where highly concentrated algal blooms typically develop in autumn, the plan was to locate a bloom, either from remote sensing or in situ information, mark the bloom by setting floats adrift in it, follow it with AUVs, and predict its development and movement with models. A secondary focus was to detect harmful algal blooms that can impact marine life, people, and the economic viability of coastal communities. Predicting the occurrence of harmful blooms is difficult, yet the effort is needed to improve warning systems and inform marine resource managers. Finally the multi-disciplinary experiment involved the first occasion that *Tethys* and a prototype of the ODSS were used in a scientific experiment.

Early in the experiment an algal bloom was observed in nearshore waters of northeastern Monterey Bay (Figure 8). Characterized by its reddish coloration—it is commonly

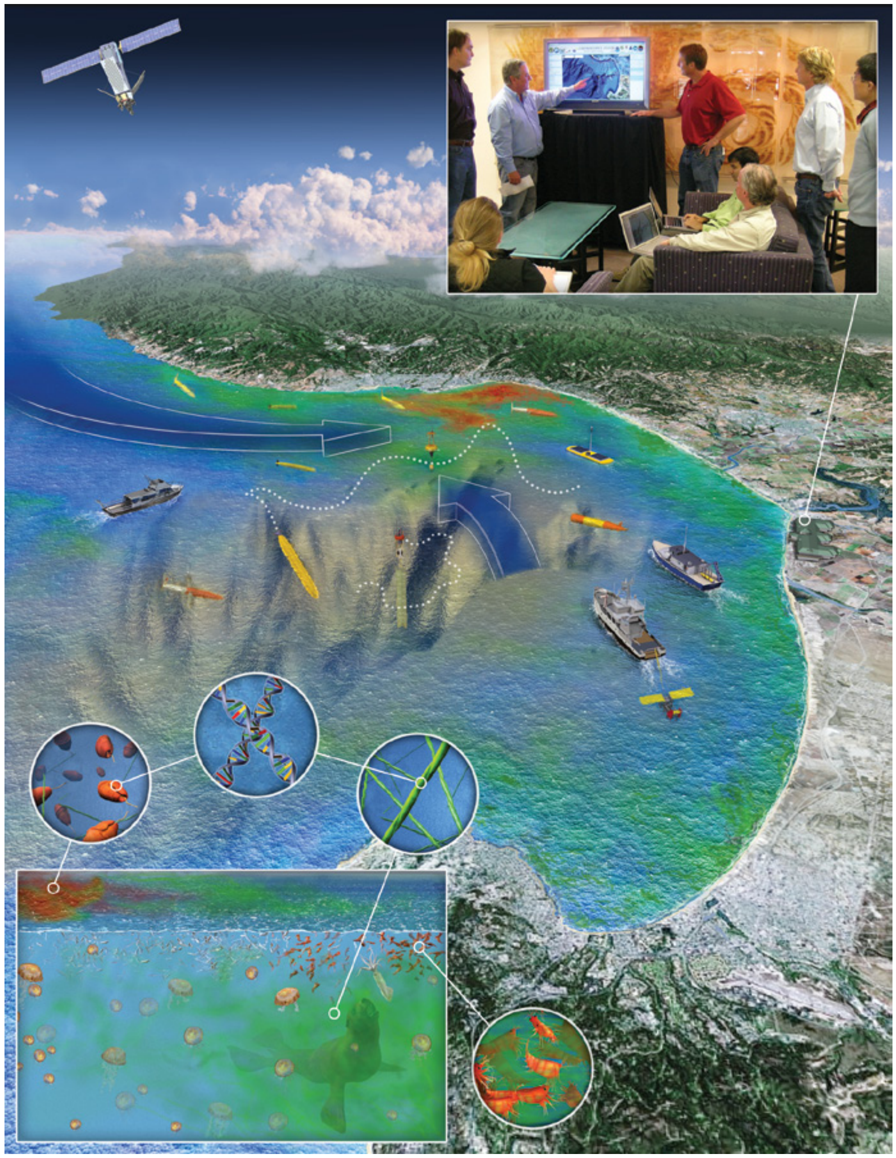


Figure 9: Illustration showing some of the platforms, techniques, and decision support tools used during the October 2010 experiment in Monterey Bay. The project brought together investigators from a dozen institutions. Red-tide and surface-swarming dinoflagellates were prominent in the north bay and domoic-acid-forming pennate diatoms were often observed at depth in the center of the bay awaiting conditions favorable for a bloom. The experiment was designed to trace domoic acid through the food chain starting with zooplankton. The upper inset shows how researchers used the Oceanographic Decision Support System (ODSS) to review real-time data and plan the location for the next day's sampling. The lower left inset shows the organisms targeted with novel genomic analyses.

described as a "red tide"—this type of bloom has been linked to seabird mortality and could contain microorganisms that contribute to the human illness known as paralytic shellfish poisoning. From its first observation in a small area of the north bay, the bloom was transported rapidly westward (Figure 8), and was subsequently detected by sensors on multiple satellites as it spread through much of the rest of northern Monterey Bay. As the evolution and extreme patchiness of the bloom was observed from space, CANON assets in the bay observed its physical, chemical, and biological conditions. The in situ observing systems confirmed that it was a red-tide bloom and identified the species present. The systems further discovered a layer of phytoplankton hiding at depth that was not detected by remote satellite sensing. ESP molecular analyses identified potential harmful algal populations in the deeper water bloom, particularly pennate diatoms suspected to cause amnesic shellfish poisoning.

The October experiment yielded new scientific information about coastal phytoplankton blooms and the processes driving them, and also heralded significant technological milestones. One involved the ability to direct autonomous vehicles to observe and acquire samples while drifting amid a feature of interest, in this case a phytoplankton bloom. Such observations are particularly relevant for CANON and for advancing understanding of the development and growth of coastal plankton. At the height of the experiment a "robotic ballet" involving *Tethys* and *Dorado* occurred. *Tethys* autonomously mapped around a drifter, providing an estimate of the bloom location relative to the drifter. The bloom location was relayed to *Dorado*, which also mapped the bloom and intelligently collected samples using its gulper water samplers. A second milestone involved the first use of the ODSS (Figure 9) as an integrated interface that informed scientists and engineers of changing environmental and biological conditions, the locations of assets, and new opportunities for collecting valuable samples.

Controlled, Agile, and Novel Observing Network

Project leads: James G. Bellingham, Francisco Chavez, Kanna Rajan, Steve Ramp, John Ryan, Chris Scholin, Ken Smith, Robert Vrijenhoek, Alexandra Z. Worden
Project manager: Francisco Chavez
Project team: Sergey Frolov, Thom Maughan

Autonomous Ocean Sampling Networks

Project lead/manager: James G. Bellingham
Project team: Sergey Frolov, Michael Godin, Thomas Hoover, Dorota Kolber, Yanwu Zhang
Collaborators: Erika McPhee-Shaw, Moss Landing Marine Laboratories, California; Robert Miyamoto, University of Washington, Seattle; James Paul, Airflow Sciences Corporation, Livonia, Mississippi; William Shaw and Tim Stanton, Naval Postgraduate School, Monterey, California; Igor Shulman, U.S. Naval Research Laboratories, Washington, D.C.

Upper Water Column Data Visualization

Project leads: Francisco Chavez, Mike McCann
Project manager: Mike McCann
Project team: Rich Schramm

Distributed Autonomy

Project lead: Kanna Rajan
Project manager: Thom Maughan
Project team: Tom O'Reilly, Frederic Py, Brent Roman, Hans Thomas
Collaborators: Daniel Borrajo, University Carlos III de Madrid, Spain; Amedeo Cesta, Institute of Cognitive Sciences and Technologies, Rome, Italy; Timothy Chung, Naval Postgraduate School, Monterey, California; Gabriel Elkaim, University of California, Santa Cruz; Maria Fox, University of Strathclyde, Glasgow, United Kingdom; Felix Ingrand, Laboratoire d'Analyse et d'Architecture des Systemes, Toulouse, France; Joao Sousa, University of Porto, Portugal; Gaurav Sukhatme, University of Southern California, Los Angeles

Long-Range AUV: Testing and Initial Operations

Project lead: James G. Bellingham
Project manager: Brett Hobson
Project team: Jon Erickson, Michael Godin, Thomas Hoover, Brian Kieft, Rob McEwen, Ed Mellinger, Yanwu Zhang

SURF Center and Probe Chemistries

(See page 19 for team members)

Expeditions

Expanding the impact of local research and development efforts beyond the confines of Monterey Bay is one of the institute's enduring themes. Ocean expeditions in 2010 included several long cruises on MBARI's own research vessels *Western Flyer* and *Zephyr* (Figure 10), as well as a geological expedition to the Arctic. MBARI also quickly mobilized to send the institute's unique upper-water-column autonomous underwater vehicle (AUV) and a team to operate it to the Gulf of Mexico to help gather data about the Deepwater Horizon oil well spill, at the request of the federal government.

Applying neotectonics to studies of the seafloor

Until recently, studies of the young deformation of Earth's crust focused primarily on terrestrial sites, where faults can be observed at the surface and sampled by trenching across them. To expand this field of study—called neotectonics—into the marine realm, MBARI geologist Charlie Paull led an R/V *Western Flyer* mission to Southern California in March, during which he focused on young seafloor faulting.

While neotectonic studies have been actively pursued on land within the Los Angeles Basin, marine neotectonics had been limited because survey and sampling tools with the needed resolution have only recently become available. High-resolution radiocarbon

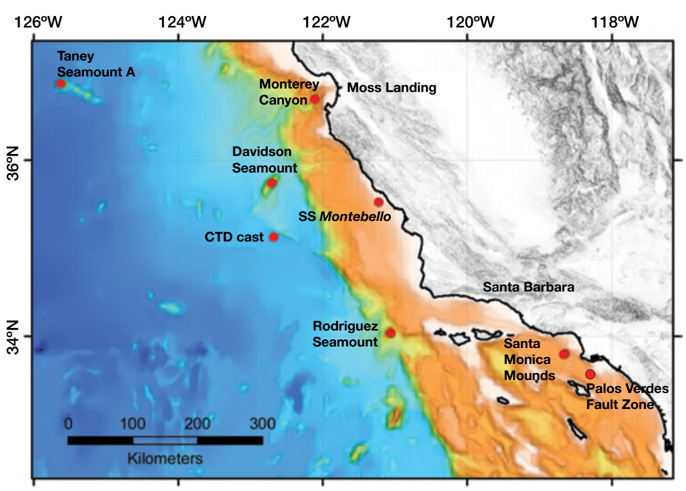


Figure 10: MBARI 2010 West Coast expedition sites. The ESP team collected water samples at the "CTD cast" site. Although Rodriguez and Davidson Seamounts were not visited in 2010, they are discussed in the section about Taney Seamount expedition.

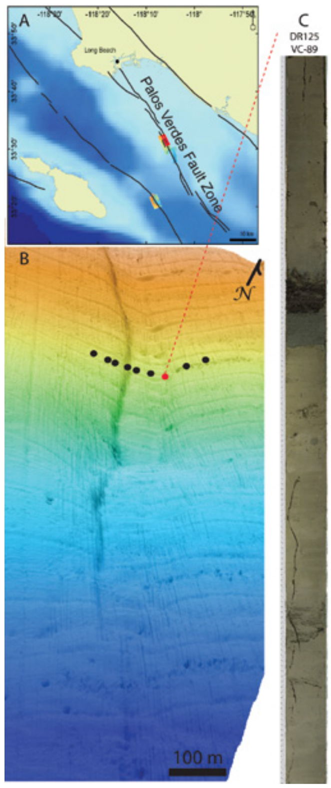


Figure 11: Location of AUV-collected bathymetric survey of the seafloor along Palos Verdes Fault is shown in part A. Part B shows a blow up of the detailed bathymetry showing one segment of the fault trace. Here a "sag pond-like" feature lies between two splays of the fault that offset the present-day seafloor. The nine dots indicate vibracores collected along one transect across the sag pond. Grid color scale covers 325-390 meters water depth. Vertical exaggeration is 20 times. Part C shows the cross section of one vibracore taken within the fault zone.

dating tools and the potential for a continuous record of undersea sedimentation promise that vastly superior records of earthquake timing and recurrence will now be possible. Through the development efforts at MBARI, tools such as the *D. Allan B.* mapping AUV and the remotely operated vehicle (ROV) vibracorer now exist for conducting detailed neotectonic surveys of the seafloor.

In 2008 the MBARI mapping AUV surveyed the seafloor associated with the Palos Verdes Fault Zone off the coast of Southern California. The resulting maps reveal small (less than one meter) scarps or abrupt drops in seafloor elevation (Figure 11) that extend throughout the survey area. These faults closely coincide with the previously identified fault zone based on profiles of low-frequency seismic sound waves reflected off the seafloor. The existence of offsets in the much higher resolution AUV data confirms that the scarps are associated with faults that cut and deform the modern seafloor in the upper 20 centimeters or less. This is arguably the youngest identified fault deformation known offshore of Southern California. When traced further upslope, this fault runs into Long Beach Harbor, the most active port facility in the United States. This deformation suggests that the subtle (10-100 meter wide) "sag ponds" or basins associated with the fault zone contain a record of the deformation history.

During the 2010 expedition, the vibracoring system on the ROV *Doc Ricketts* was used to collect cores along transects spaced 25 meters apart across the fault and sag ponds along the Palos Verdes Fault Zone. Core spacing at such fine intervals could be done in part because of the ROV pilots' skills and in part because the subtle fault scarp could be located using the ROV's scanning sonar, thus confirming the position of the ROV-collected cores to sub-meter accuracy with respect to the fault. The co-occurrence of transported shell fragments, layers rich with woody material, and foraminifera provided information for resolving the chronology of deformation in considerable detail using carbon-14 accelerated mass spectrometry dating. By coupling the high-resolution AUV mapping surveys and surgical sampling using an ROV, this study is revealing the character of recent seafloor fault deformation in unprecedented detail.

Continental Margin and Submarine Canyon Processes

Project lead: Charles Paull

Project manager: William Ussler

Project team: Krystle Anderson, Larry Bird, David Caress, Brett Hobson, Eve Lundsten, Gene Massion, Melissa Meiner, Brian Schlining

Collaborators: Clark Alexander, Skidaway Institution of Oceanography, Savannah, Georgia; Jamie Conrad, Brian Edwards, and Mary McGann, U.S. Geological Survey, Menlo Park, California; Scott Dallimore and Michael Riedel, Natural Resources Canada, Sidney, British Columbia; Char-Shine Liu, National Taiwan University; Thomas Stevens, Royal Holloway, Surrey, United Kingdom; Peter Talling, National Oceanographic Centre, Southampton, United Kingdom

Remote detection of microbes in the deep

The deep waters of Santa Monica Bay support a thriving community of organisms despite the fact that there is very little oxygen, no light, and near freezing temperatures. This site laid the essential foundation for a project sponsored by NASA's astrobiology program. The challenge set forth by NASA is to devise tools and techniques for detecting microbial life without a human presence, as a model for searching for life on other planets. A milestone towards meeting that objective was achieved with the deployment of the Deep-Sea Environmental Sample Processor (D-ESP) on the seafloor of Santa Monica Bay during the *Western Flyer*'s Southern Expedition.

The MBARI-developed D-ESP is an autonomous seafloor laboratory that uses advanced microfluidic and genomic techniques for investigating microbes in seawater. This seafloor laboratory has significant advantages over shore-based laboratory investigations of water samples collected from the deep sea using traditional ship- and ROV-based techniques. By collecting and analyzing samples in situ, the D-ESP avoids perturbations associated with bringing samples to the surface—change in pressure, exposure to light, and wide temperature fluctuations—that typically occur during traditional laboratory analyses. The D-ESP is also equipped with a suite of sensors that measure the chemical and physical conditions in the immediate surroundings, providing an environmental context for the local microbial community. Conducting in situ analyses using the D-ESP enables remote assessment of the microorganisms that inhabit the deep sea and an improved understanding of how the physical and chemical environment controls their distribution and activity (Figure 12).

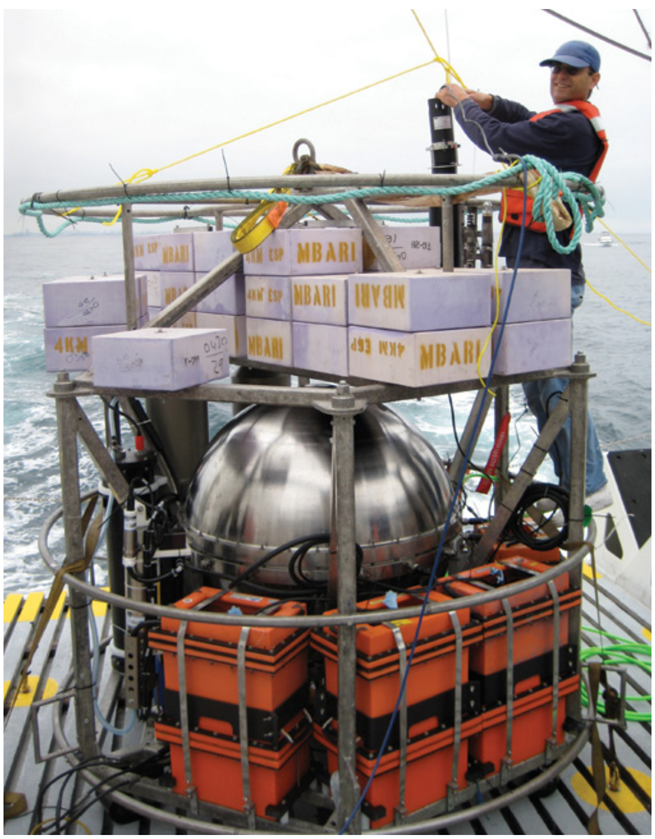


Figure 12: MBARI Electrical Engineer Scott Jensen prepares the D-ESP for deployment to the northeast Santa Monica Mound.

To fully test the capabilities of the instrument, the D-ESP research and development team, headed by MBARI President Chris Scholin and engineer Jim Birch, targeted a site known to have high concentrations of methane and abundant methane-consuming bacteria in the seawater. They chose a prominent bump on the seafloor known as the northeast Santa Monica Mound, which is 20 miles offshore from Los Angeles, at a depth of 800 meters in Santa Monica Bay. This isolated mound is about 100 meters in diameter and rises approximately 10 meters above the surrounding seafloor. The mound is constructed primarily of calcium carbonate derived from the microbial oxidation of methane gas trapped in sediment just below the seafloor. Long cracks on the mound surface release some of this trapped methane as continuous streams of gas bubbles. A colorful mosaic of orange and white bacterial mats covers the mound and extensive chemosynthetic clam communities surround it. These organisms obtain their energy by oxidizing the dissolved hydrogen sulfide that is diffusing out of the mound.

The methane-consuming bacteria in the water column above the mound were identified previously using laboratory genomic techniques developed by collaborators at the California Institute of Technology, then adapted to the analytical method used by the D-ESP. This method targets a portion of the gene that encodes the last enzyme in a series of biochemical steps that converts methane into carbon dioxide, releasing energy needed to sustain the bacteria. Methane is a major energy and carbon source for organisms residing in the deep sea. Complex ecosystems comprised of organisms adapted to a methane-consuming lifestyle form distinct oases wherever methane is emanating from the seafloor.

The D-ESP was deployed on the crest of the mound and at nearby locations to determine if the amount of methane

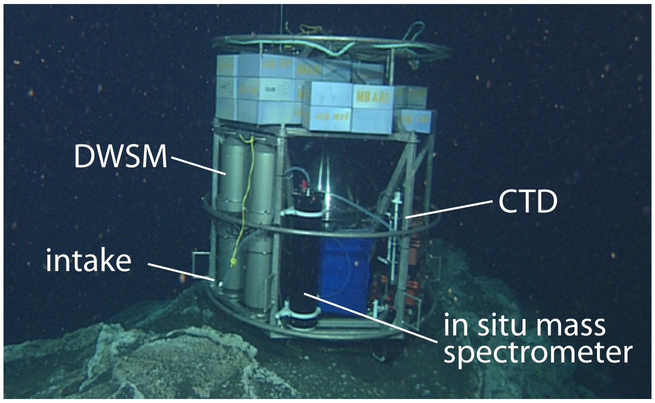


Figure 13: The D-ESP perches precariously on the crest of the northeast Santa Monica Mound. The Deep Water Sampling Module (DWSM) takes a sip of seawater through the intake, depressurizes it, and sends it to the analytical equipment inside the titanium sphere. The in situ mass spectrometer measures the methane concentration in the surrounding water; the CTD (conductivity, temperature, and depth) instrument provides contextual information for analyzing the samples.

SURF Center (Sensors: Underwater Research of the Future): Applications of the Second-Generation Environmental Sample Processor and Probe Chemistries for Use with the ESP

Project leads: James Birch, Chris Scholin

Project manager: James Birch

Project team: Elif Demir-Hilton, Kevin Gomes, Julio Harvey, Allison Haywood, Scott Jensen, Roman Marin III, Gene Massion, Doug Pargett, Christina Preston, Brent Roman, John Ryan, William Ussler

Collaborators: Don Anderson, Woods Hole Oceanographic Institution, Massachusetts; Dave Caron and Burt Jones, University of Southern California, Los Angeles; Laurie Connell, University of Maine, Orono; Ed DeLong and Elizabeth Ottesen, Massachusetts Institute of Technology, Cambridge; Gregory Doucette, National Ocean Service Marine Biotoxins Laboratory, Charleston, South Carolina; Clement Furlong, University of Washington, Seattle; Peter Girguis, Harvard University, Cambridge, Massachusetts; Cindy Heil, Florida Fish and Wildlife Conservation Commission, St. Petersburg; Deirdre Meldrum, Arizona State University, Tempe; Mary Ann Moran and Vanessa Varaljay, University of Georgia, Athens; Victoria Orphan, California Institute of Technology, Pasadena; Julie Robidart and Jonathan Zehr, University of California, Santa Cruz; Robert Vrijenhoek, MBARI

in the water correlates with the abundance of methane-consuming bacteria (Figure 13). Methane concentrations were measured either by taking discrete water samples with traditional Niskin bottles and analyzing these samples using a specialized shipboard gas chromatograph, or by measuring methane concentration using an in situ mass spectrometer attached to the D-ESP. (The mass spectrometer was recently developed by MBARI and collaborators at Harvard University.) Results showed that an increase in methane-consuming bacteria occurs not only just above the crest of the northeast Santa Monica Mound, but also in the general vicinity of the mound. This enrichment of bacteria did not correlate with the seawater's methane concentration, which drops dramatically with distance from the mound. This result suggests that other factors control the abundance and distribution of methane-consuming bacteria adjacent to areas where methane is leaking out of the seafloor.

Marine microbiologists face a formidable challenge in understanding the microbial world that inhabits our oceans. Most microbes in the ocean cannot be cultured and studied in the laboratory. The alternative is to study them in their own habitat. The development of the D-ESP is one small step towards achieving that goal.

The dual effects of global warming and ocean acidification

On another leg of the Southern Expedition, MBARI chemist Peter Brewer tested the combined effects of low oxygen and high carbon dioxide concentrations on important species of marine invertebrates and investigated the chemistry of the water within the sediments (pore water). Both of these projects are well suited to the Southern California region because of an intense oxygen-minimum zone in the basins just offshore and the accumulation of anoxic sediments in these basins. The strong oxygen minimum in the midwater (between 400 and 800 meters depth) is the product of strong coastal productivity combined with the local water circulation pattern, which only rarely flushes deep water from these basins. As the organic matter from coastal productivity descends through deeper water, some of it is consumed by bacteria in a process that depletes the oxygen in the water. Because deep waters circulate and renew very slowly, the oxygen is almost completely depleted. Likewise, this steady rain of material accumulates in the basins where bacteria quickly consume what little oxygen there is in the pore water. As the sediments become anoxic, the bacteria turn to the oxygen-bearing sulfate in the pore water in order to continue consuming organic matter. As a result, the sediment pore waters become rich in both carbon dioxide and hydrogen sulfide.

Conducting experiments in such conditions gives researchers insight into how the combined impact of global warming and increased carbon dioxide in the ocean will affect the respiration of marine organisms. Warm seawater contains less oxygen than cold seawater. So as the ocean warms due to the enhanced greenhouse effect, less and less oxygen is absorbed by the upper layer of the ocean. At the same time, carbon dioxide in the atmosphere from the burning of fossil fuels is now invading the ocean at a rate of one million tons of carbon dioxide per hour worldwide.

As a consequence, animals find it harder to "breathe." Brewer's team used the natural laboratory of coastal basins to conduct experiments exploring how the increased CO_2 and decreased oxygen affect the behavior of marine animals and what thresholds endanger their lives.

A large detritus sampler on the swing-arm of ROV *Doc Ricketts* was used to collect the animals for study. The clear container had been specially rigged to expose a captured animal to high levels of carbon dioxide and low oxygen. Actively swimming squid in the chamber quickly changed behavior when the carbon dioxide was increased. One squid almost immediately stopped swimming, then exhibited dramatic color changes and occasional bursts of activity. Finally, with little energy left, it sank to the bottom of the chamber and beat its gills in an effort to obtain the last little bit of oxygen that remained in the seawater and get rid of the carbon dioxide that had accumulated in its blood (Figure 14).

The small squid was then released back into the ocean where lower carbon dioxide levels and slightly higher oxygen concentration quickly revived the animal. After one or two minutes, the squid quickly swam away. Repeating the experiment several more times with different individuals revealed the same pattern of behavior.

These experiments, along with work on similar species in Monterey Bay, revealed a general pattern of sensitivity to the combined effects of low oxygen and high carbon dioxide. While different species show different levels of sensitivity to rising carbon dioxide and low oxygen, there is evidence of a threshold where no aerobic life is possible. In addition, the combined effects of global warming (leading to lower oxygen levels) and the invasion of anthropogenic carbon dioxide into the ocean will lead to an expansion of the oxygen minimum zones in the world ocean and the proliferation of dead zones along the coastal margins.

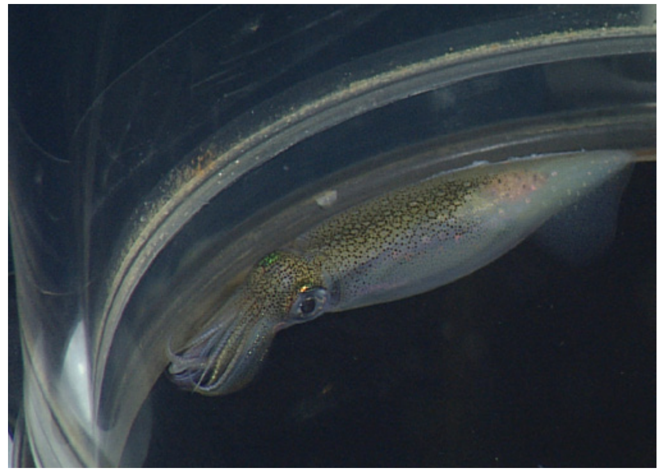


Figure 14: A small squid lying docilely on the bottom of a detritus sampler. A rapidly swimming squid was captured by the ROV pilots and then the CO_2 level of the seawater in the chamber was increased to approximate the expected levels of seawater CO_2 concentrations in the next century. The squid stopped swimming for several minutes. After 10 to 15 minutes of observations, the squid was released and it quickly revived.

After several days of respiration experiments, Brewer's team turned its attention to the use of the laser Raman spectrometer (LRS) to investigate the pore-water chemistry of the sediments in the coastal basins. The chemical pathway creating anoxic marine sediments is relatively well known and implies a precise inverse relationship between the abundances of sulfate and hydrogen sulfide. Since both compounds are Raman active, a single series of probe analyses at different depths into the sediment serves to reveal the profile of both sulfate and hydrogen sulfide. In addition, with methane supplied from reactions deep in the sediment, and sulfate diffusing in from the overlying seawater, an inverse correlation between sulfate and methane is also expected (Figure 15).

Using ROV surveys of the seafloor to locate areas near a gas vent or cold seep allowed for precise placement of the pore-water probe (Figure 16). As the probe was inserted into the sediments, the detected chemical profiles were observed in real-time at each of several depths. The initial objective in this work was to explore the pore-water profiles in close proximity to two known gas vents. This work proved successful as the team was able to place the pore-water probe precisely and gather profiles next to and successively further from the vents.

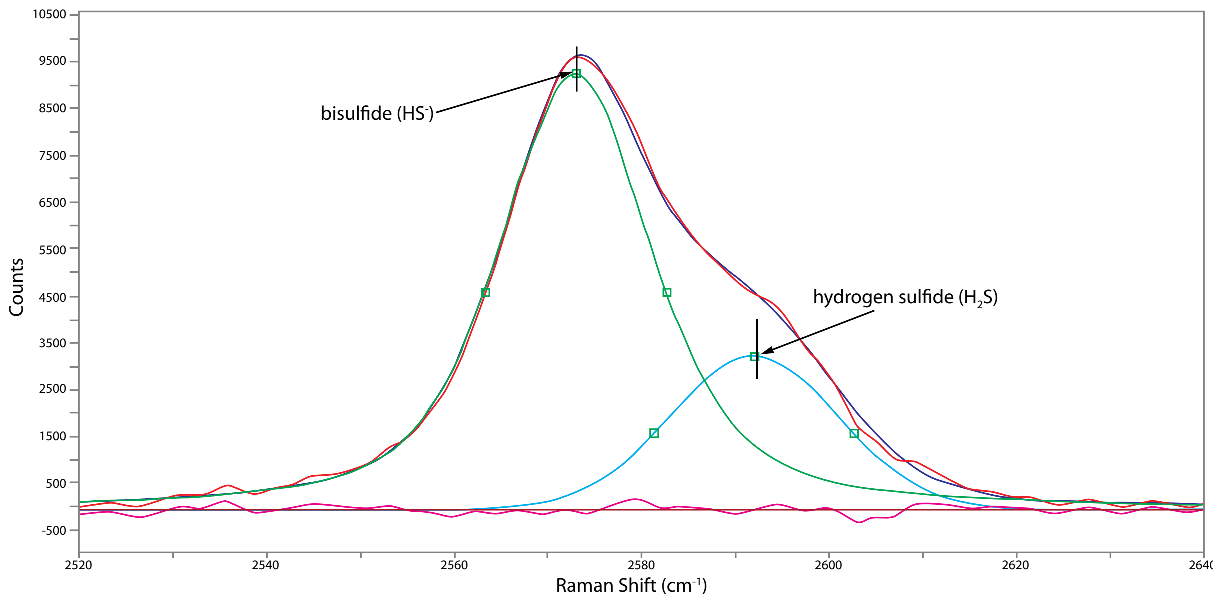


Figure 15: Laser Raman spectrum of anoxic pore waters of seafloor sediments in the Santa Monica basin shows strong signals of hydrogen sulfide and bisulfide. The ratio of these two chemical species is directly related to pH. Once the response of the spectrometer is fully calibrated for the relative response of these two species researchers can directly determine the pH of the sediment pore waters.

A secondary target provided the greatest surprise of the cruise. Of the two Santa Monica Mounds previously detected by geologist Charlie Paull using AUV mapping, the shallower was known to be actively venting gas and was considered the more interesting target. Although there was abundant marine life on the shallow mound—clams, crabs, and snails clustered around the vent sites—the deep mound was eerily void of visible animals. Instead, the seafloor was covered with a thick blanket of a snow-white bacterial mat. And while this site provided many nice pore-water profiles, it was the lack of aerobic organisms that provided the greatest insight. With the small change in water conditions from the shallower mound to the deeper mound, the slightly lower oxygen concentrations and slightly higher dissolved carbon dioxide were sufficient to indicate a biochemical boundary. At one site aerobic life was possible; on the other site it was not. The threshold that the team of chemists had labored to find with respiration experiments earlier in the cruise was apparent in a totally natural environment.

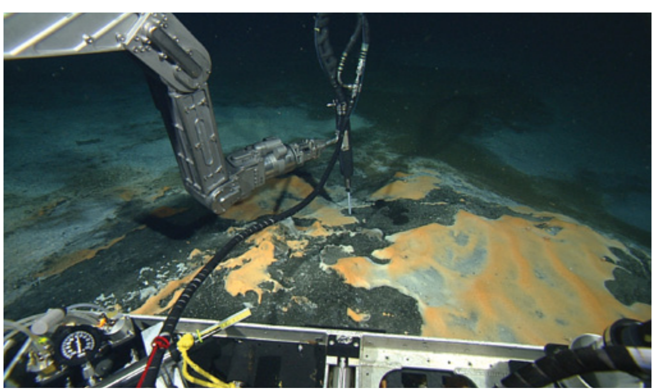


Figure 16: The laser Raman spectrometer pore-water probe is seen inserted about 20 centimeters into the seafloor in the Santa Monica basin. The thick bacterial mat is growing at the interface of low oxygen seawater and anoxic sediments. The pore-water probe measures in situ the concentrations of sulfate, hydrogen sulfide, and methane. If sediment cores were brought to the surface for laboratory analysis, depressurization of the core would cause much of the gas to escape on the way up.

Based upon this discovery, a new AUV “mapping” experiment is planned in this area. Instead of mapping the seafloor, the AUV will map the chemistry of the overlying water column to look for the “aerobic respiration threshold.”

Ocean Chemistry of the Greenhouse Gases

Project leads: Peter G. Brewer, William Kirkwood
Project manager: Edward Peltzer
Project team: Andreas Hofmann, Peter Walz
Collaborators: Stephen Kirby, John Pinkston, and Laura Stern, U.S. Geological Survey, Menlo Park, California; Zhigang Zeng and Xin Zhang, Chinese Academy of Sciences, Qingdao

Seafloor mapping enables detailed seamount study

Several types of volcanoes form on or near ocean spreading centers where seafloor is created as crustal plates move apart. An unusual type of volcano grew on top of spreading centers that are no longer active offshore of Southern California, forming elongate ridge-shaped seamounts oriented parallel to the underlying spreading center. These include Davidson, Pioneer, and Rodriguez Seamounts. A different type of volcano forms adjacent to active spreading centers. These are active for only a short period, until they get cut off from their magma supply as the distance between the seamount and active mid-ocean ridge increases due to seafloor spreading. At some spreading centers these volcanoes are fairly common; they are characterized by having large, deep calderas both in their summits and cutting their flanks.

Three chains of such seamounts—each chain a different age—occur in the waters off the West Coast of the United States. The youngest is the Vance Seamount chain, located just west of the Juan de Fuca Ridge off Oregon, where six ROV dives were completed in 2006. A thick section of volcaniclastite (fragmental volcanic rocks that have been transported and deposited) was discovered on one of the Vance Seamounts; that section will be a sampling and mapping target in 2011. Next oldest is the President Jackson Seamount chain, located west of the Gorda Ridge off Northern California, where five ROV dives were completed in 2000, 2002, and 2009. The oldest is the Taney Seamount chain, west of Monterey Bay, where eight dives were completed in 2000 and 2010. Each of these seamounts has experienced one or more caldera collapses and deposition of thick volcaniclastic sections on their rims, like the active Axial Seamount that straddles the Juan de Fuca Ridge, where extensive studies have been conducted over the past five years.

The Taney Seamounts have been reluctant to give up their secrets. Volcanologist Dave Clague first became interested in these seamounts in 1980 on a U.S. Geological Survey (USGS) cruise when several dredges recovered pillow lavas and volcaniclastite from two of the Taney Seamounts. At the time, single-beam bathymetric surveys suggested that these volcanoes might have summit depressions with flat caldera floors. When Clague joined the MBARI staff, he renewed his study of the Taney Seamounts and included them in MBARI's first large multibeam swath surveys in 1998. These 40-meter-resolution maps clearly showed that these seamounts had large and deep calderas. Two ROV *Tiburon* dives were completed two years later on the two easternmost seamounts.

In 2010, the R/V *Zephyr* traveled to the Taney Seamounts, where the MBARI mapping AUV *D. Allan B.* collected high-resolution mapping data. This cruise was followed with a series of ROV *Doc Ricketts* dives using the new maps. The plan to study the Taney Seamounts was plagued with technical problems. Only one of five planned mapping missions was completed. That sole survey was the most complex survey attempted by the *D. Allan B.*, as the vehicle had to traverse down steep slopes that separated three different depth levels (Figure 17).

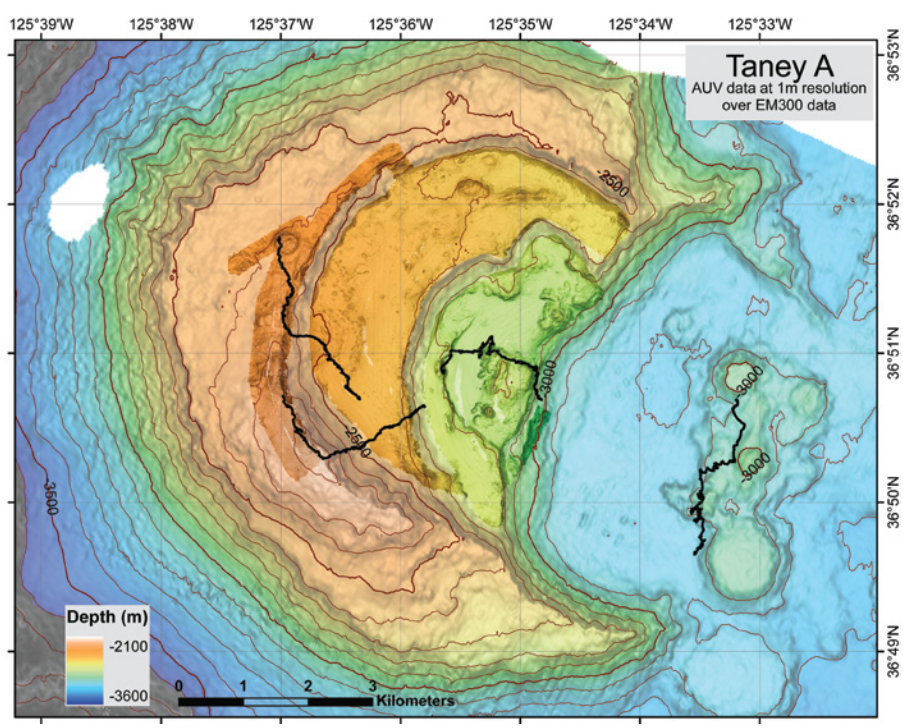


Figure 17: Map of Taney Seamount A (the westernmost of the chain) showing high-resolution AUV data superimposed on lower-resolution multibeam data collected in 1998. Three calderas have formed sequentially to the east, and the youngest, and deepest, caldera has several flat-topped cones on the floor. ROV *Doc Ricketts* dive tracks are black lines.

Figure 18: A volcaniclastic deposit of ash and lava fragments on the caldera rim cemented with manganese crust. It is substrate for a brisingid seastar, several brittlestars, a yellow stalked crinoid, and white and purple sponges (2,916 meters depth).

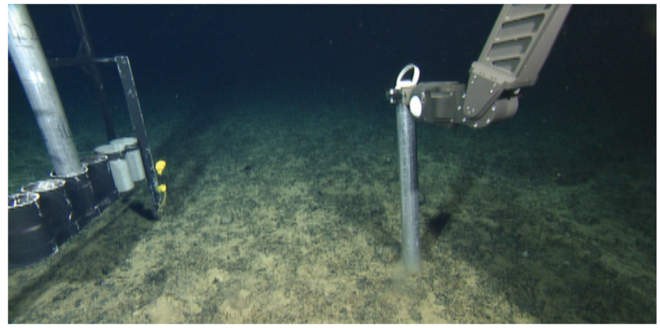


Figure 19: Long core being pushed into thick sediment on the caldera floor (3,329 meters depth).

The new mapping data imaged the western rim and two successively deeper caldera floors, of the westernmost seamount. A third, even deeper, but unmapped caldera floor occurs to the east. The caldera floors are extremely smooth and show no evidence of pillowed lava flow margins or lava channels seen in the caldera at Axial Volcano, which suggests that the caldera floors are buried in sediment. Other features revealed by the new mapping data include a structure at the base of one of the caldera walls that appears to be lava that cascaded over the caldera wall, near-vertical caldera walls, outward directed lava channels on the rim, and clusters of small volcanic cones on the floor of the youngest and deepest caldera floor.

When the *Western Flyer* headed out with Clague's group a few days after new maps were created, the dive plan was adjusted to focus on the westernmost seamount, with four dives on that seamount. One dive was also made on each of two of the other seamounts. This time, the weather cooperated. These older seamounts are particularly challenging to sample because manganese-oxide crusts have been accumulating on and cementing the rocks since the seamounts formed about 26 million years ago (Figure 18). Nonetheless, the researchers collected hundreds of samples and push cores for analysis (Figure 19). Microscope slides of the rocks, the first chemical analyses of the lavas, and some climatic and age studies on the long cores are under way.

The samples are some of the oldest recovered from near-ridge seamounts and will aid the evaluation of the Pacific-Farallon spreading ridge before the ridge became inactive and the San Andreas fault system was born.

Submarine Volcanism

Project lead: David Clague
Project manager: Jennifer Paduan
Project team: David Caress, Isobel Yeo
Collaborators: Michael Bizimis, University of South Carolina, Columbia; Julie Bowles, University of Minnesota, Twin Cities; Juan Carlos Bragam, University of Granada, Spain; William Chadwick, Robert Duncan, and John Huard, Oregon State University, Corvallis; Brian Cousens, Carleton University, Ottawa, Canada; Jacqueline Dixon, University of Miami, Florida; Brian Dreyer, James Gill, Don Potts, and Christina Ravelo, University of California, Santa Cruz; Bob Embley, National Oceanic and Atmospheric Administration, Newport, Oregon; Fred Frey and Guangping Xu, Massachusetts Institute of Technology, Cambridge; Paul Fullagar, University of North Carolina, Chapel Hill; Jim Hein, Rozalind Helz, James Moore, Stephanie Ross, and David Sherrod, U.S. Geological Survey, Menlo Park, California; Tessa Hill, Jim McClain, Peter Schiffman, and Rob Zierenberg, University of California, Davis; David Hilton and Jerry Winterer, Scripps Institution of Oceanography, La Jolla, California; Sichun Huang, Harvard University, Massachusetts; Deborah Kelley and Joseph Resing, University of Washington, Seattle; Chris Mah, Smithsonian Institution, Washington, D.C.; Kathie Marsaglia, California State University, Northridge; Craig McClain, University of North Carolina, Durham; Michael Perfit, Florida State University, Tallahassee; Willem Renema, Leiden University, the Netherlands; John Stix, McGill University, Montreal, Canada; Jody Webster, University of Sydney, Australia

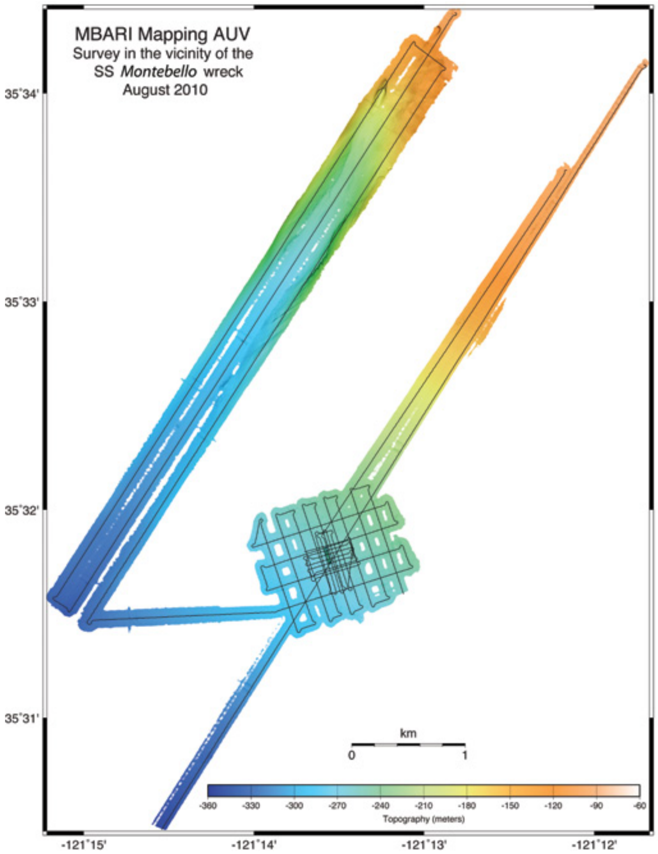


Figure 20: AUV mission tracks and multibeam bathymetry in the vicinity of the SS *Montebello* wreck. The initial two AUV missions over the wreck were flown 75 meters above the seafloor to avoid any fishing nets that might be snagged on the wreck. The small submarine canyon to the northwest, Montebello Canyon, has a smooth morphology, is not connected to a sediment source, and is likely not an active focus of significant sediment transport.

Gauging risks posed by an aging shipwreck

A very different mission for the MBARI mapping AUV in 2010 involved a survey of a sunken oil tanker that has rested on the seafloor since World War II. The SS *Montebello*, a Union Oil Company tanker torpedoed and sunk on December 23, 1941, lies about 11 kilometers off of the coast of Cambria, California, at a depth of 265 meters. The 134-meter-long vessel was loaded with 73,471 barrels (approximately three million gallons) of crude oil; there is no evidence that significant leakage of that cargo occurred at the time of sinking or in the 69 years since.

Long known as a fishing hot spot, the *Montebello* wreck was explored with NOAA funding using a small human-occupied submersible in 1996 and 2003. These dives established that the vessel was largely intact, but deteriorating. Concern about the potential for the release of the tanker's cargo led to the formation of a multi-agency government task force in 2009. The task force commissioned the MBARI AUV survey as part of its effort to assess the potential pollution threat. The survey data will be used to determine the extent and general character of the wreckage for a pending task force report and to guide any future ROV dives or assessment activity.

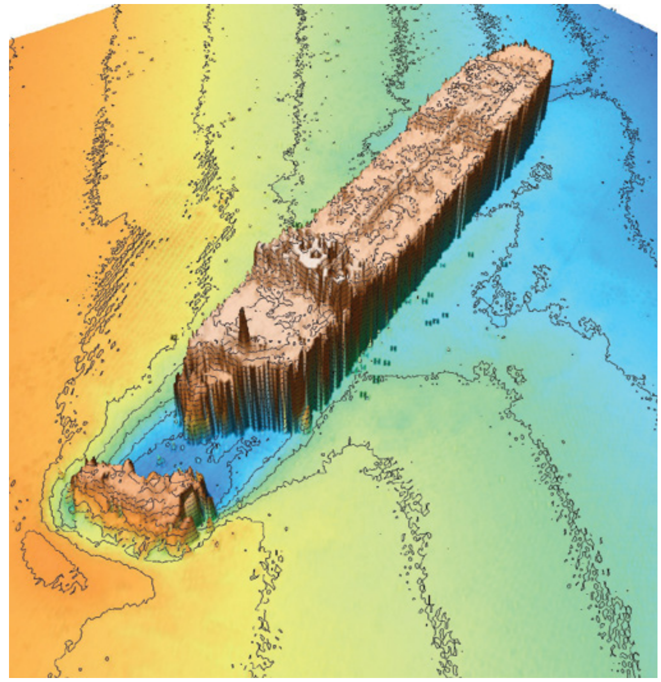


Figure 21: Multibeam bathymetry of the *Montebello* wreck. The bow can be seen broken off in the lower left corner. The image includes contours of the surrounding seafloor.

The first of three AUV missions launched from the R/V *Zephyr* consisted of a single transect over the wreck running down the slope from 90 meters depth to 350 meters depth. A second survey covered a small submarine canyon to the northwest, then ended with a survey of the *Montebello* site (Figure 20). The final AUV mission was a high-resolution survey both parallel and orthogonal to the wreck. The multibeam bathymetry outlined the wreck from above and from the sides with half-meter lateral resolution.

Analysis of the bathymetry and the subbottom profiles yielded significant observations. The ship's bow was separated from the rest of the hull, tilted forward, and partially buried. Aside from the bow, the vessel is largely intact and upright (Figures 21 and 22). Both the bridge and the aft

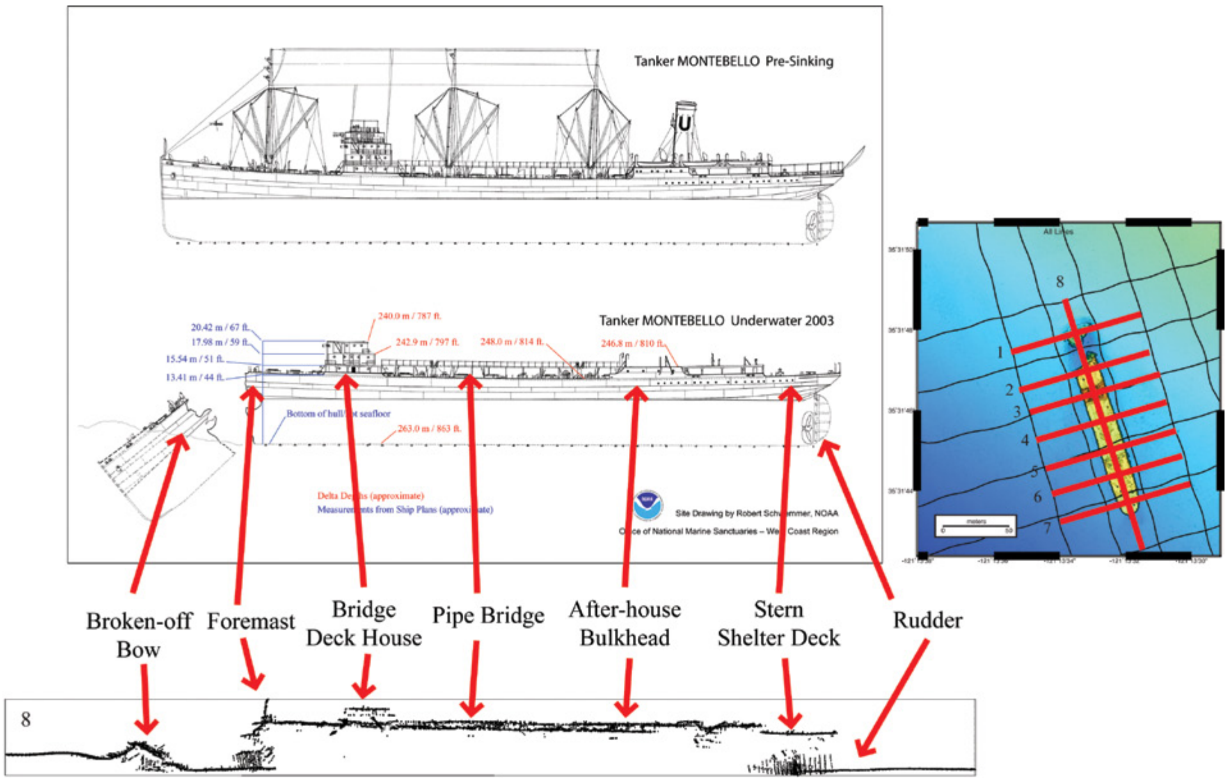


Figure 22: Comparison of the original ship plans, the wreck interpretation derived from submersible observations by Robert Schwemmer of NOAA, and the soundings along a north-south section.

deckhouses are intact, as is the pipe bridge running along the main deck and the shelter deck on the stern. The foremast is at least partly intact, but the aft two masts and the stack are missing. The rudder is intact, but leaning to port. The vicinity of the wreck has not recently been subject to significant sediment deposition or erosion, and there were large schools of fish near the wreck. There is no evidence of large downslope movement or slope instability in the vicinity of the wreck.

The bathymetry data indicate that the *Montebello* was pitched forward down when it hit the seafloor, crushing and breaking off the bow section. Except for the bow and the stack, the wreck is largely intact.

Seafloor Mapping Data Support/MB-System

Project lead/manager: David Caress
Project team: David Clague, Doug Conlin, Eve Lundsten, Jennifer Paduan, Charles Paull, Hans Thomas, Duane Thompson
Collaborator: Dale Chayes, Lamont-Doherty Earth Observatory of Columbia University, New York

SS *Montebello* Wreck Survey

Project lead: David Caress
Project manager: Chris Grech
Project team: Charles Paull, Hans Thomas

Unique AUV aids in assessing Gulf of Mexico oil spill

The largest marine oil spill in the history of the petroleum industry began in late April 2010 following an explosion on the BP Deepwater Horizon drilling platform in the Gulf of Mexico. Total destruction of the platform and loss of control of the wellhead 5,000 feet below initiated a massive environmental disturbance. Mitigation efforts to stop the blowout employed ROVs to evaluate the damaged wellhead and to cap it. Efforts to protect coastal environments employed satellites and aircraft to detect the oil and its movement, and a variety of systems to remove, disperse, or block surface oil plumes.

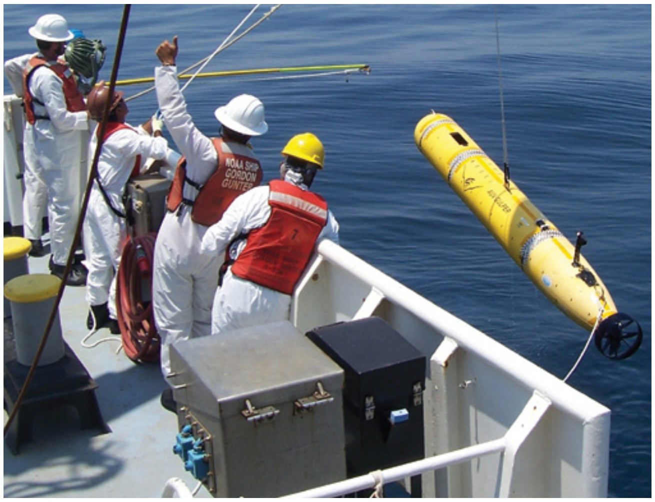


Figure 23. Recovery of the *Dorado* AUV following a mission in the Gulf of Mexico.

Although response efforts yielded information on the surface and bottom boundaries of the disaster, the vast volume of ocean between the boundaries was largely unknown. Early observations from ships indicated that large plumes of oil, dispersed at the wellhead itself, were remaining in the deep ocean, between 1,000 meters and 1,500 meters deep, rather than rising to the surface. However, the existence of deep oil plumes was highly controversial. This controversy, and the need to gather data for an informed resolution, led to a request from NOAA to deploy a unique MBARI technology—the *Dorado* autonomous underwater vehicle (Figure 23).

Like other rapid responders, MBARI adapted existing technology for a new and pressing problem. The capabilities and reliability of *Dorado*, developed for studying complex coastal waters, made it adaptable to meet the requirements of studying deep oil plumes in the Gulf of Mexico. In the Monterey Bay region, *Dorado* has supported a great variety of studies in coastal oceanography, including plankton ecology, ocean physics, sediment transport emanating from the continental shelf and slope, and land drainage into coastal waters. With its gulper sampling system, *Dorado* employs onboard intelligence to acquire water samples from targeted features of interest. This sampling system was designed to handle high pressure in deepwater deployments, so it was ready for sampling deep hydrocarbon plumes in the Gulf of Mexico. An optical fluorescence sensor capable of detecting hydrocarbons was added to the AUV. Following the rapid adaptation and mobilization of *Dorado*, the MBARI team embarked on a cruise to help fill the large information gap in the Gulf.

A survey of the oil spill region took place between May 27th and June 4th, 2010, on the NOAA ship *Gordon Gunter*. In addition to *Dorado*, the ship carried a conductivity, temperature, depth (CTD) sensor system to measure water properties and acquire samples of clean and oil-polluted Gulf water.

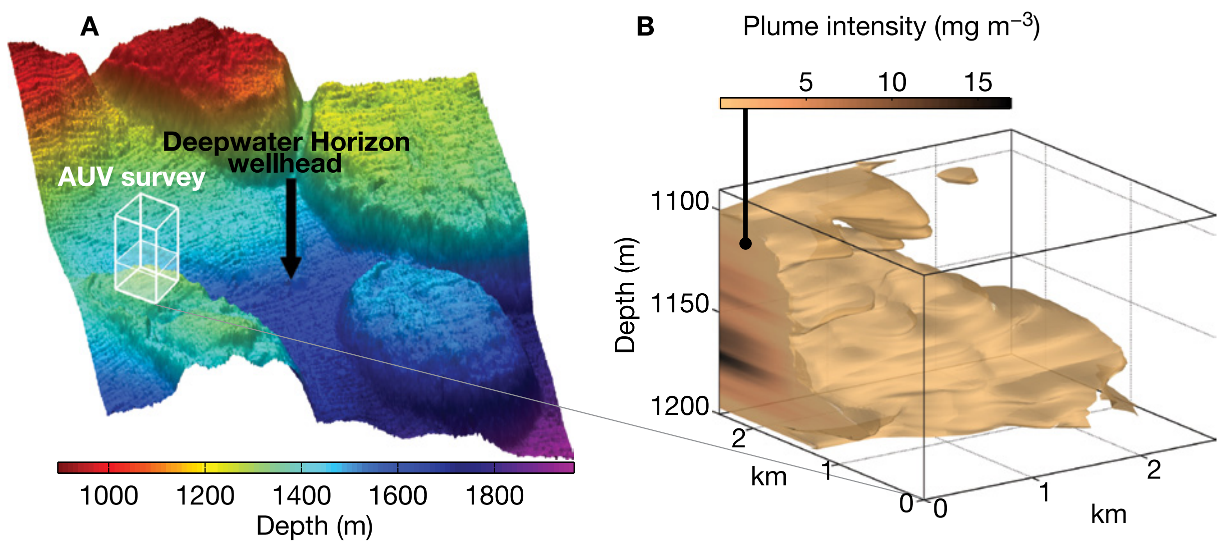


Figure 24. (A) Bathymetry around the Deepwater Horizon wellhead, where the *Dorado* AUV mapped the boundary and interior structure of a deep hydrocarbon plume. (B) Illustration of the plume from AUV data acquired on June 3rd, 2010. The spatial domain shown corresponds with the highlighted lower portion of the AUV survey volume in (A). Plume intensity was quantified using data from a colored dissolved organic matter (CDOM) fluorometer on the AUV and is represented in units of above-background concentration. Samples were returned for laboratory analysis to identify and quantify the chemical compounds in the plume.

Also onboard was an acoustic system developed for studies of marine life and considered to be a potentially effective tool for mapping deep oil plumes. The survey identified a region southwest of the wellhead where signals of a deep plume were strongest, and so during the final two days of ship operations, *Dorado* was deployed to autonomously map and sample the plume.

Dorado surveys mapped a region of the plume boundary and interior, revealing its complex structure (Figure 24). The plume signal was found primarily between 1,100 and 1,200 meters depth (Figure 24B), consistent with visual observations from ROVs southwest of the wellhead. The software for autonomous plume recognition and sampling was successfully tested.

With short time for testing and little room for error, the MBARI team proved the effectiveness of *Dorado* and provided valuable data on a feature of great interest. The effort helped fill a vast information gap and informed subsequent observational efforts in the same region. Through greater collaborative efforts in the following months, a persistent hydrocarbon plume southwest of the wellhead was identified and linked to its source from the Deepwater Horizon wellhead.

The thawing Arctic seafloor

As global climate change results in the shrinking of the Arctic ice cap, researchers are making new discoveries about this ocean basin. Recent surveys revealed evidence suggesting gas venting and features characteristic of an unstable seafloor. These features were observed along the edge of the continental shelf where gas venting is predicted to occur as a consequence of regional warming. The recent retreat of the ice cover in the Arctic has made collecting detailed bathymetry here easier. Systematic seafloor mapping is now being conducted in this area that was historically covered in ice year round. To provide ground-truth observations and sampling to corroborate these discoveries, MBARI geologist Charlie Paull and engineers Dale Graves and Alana Sherman joined Canadian scientists on an expedition on the Canadian Coast Guard icebreaker *Sir Wilfrid Laurier* to the Beaufort Sea in the Canadian Arctic.

For this expedition, MBARI provided a small ROV to investigate the seafloor and collect gas samples (Figure 25). MBARI's participation in this expedition (funded in part by the USGS) was intended to evaluate the feasibility of using ROVs to document methane releases from the seafloor on the Arctic continental shelf.

Methane hydrate is an ice-like solid formed from methane and water in which the methane molecules are trapped in a cage of water molecules. Both permafrost and methane

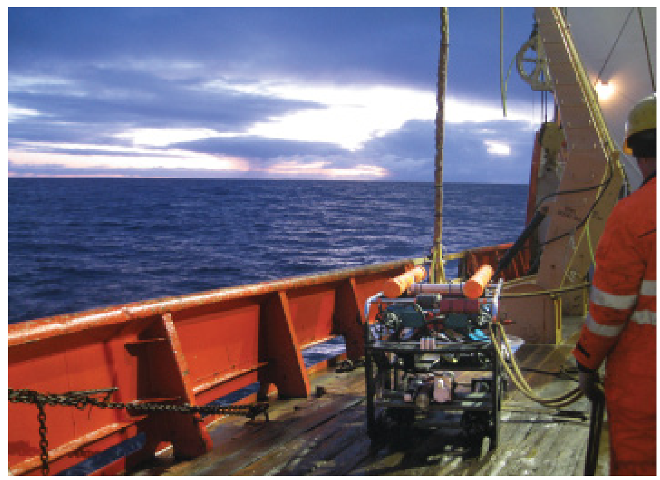


Figure 25: The ROV is prepared for launch from the *Sir Wilfrid Laurier* into ice-free waters at approximately 71° N in October.

Figure 26: Escaping gas bubbles (red arrow) from near the edge of the shelf in the Beaufort Sea of the Canadian Arctic.

Rapid Response to the Deepwater Horizon Disaster in the Gulf of Mexico

Project leads: Steve Etchemendy, Chris Scholin

Project manager: Hans Thomas

Project team: Larry Bird, Mike McCann, Erich Rienecker, John Ryan, Yanwu Zhang

Collaborators: Richard Camilli and Robert Nelson, Woods Hole Oceanographic Institution, Massachusetts; Shailer Cummings, Samuel Walker, and Zdenka Willis, National Oceanic and Atmospheric Administration hydrates that were stable in the subsurface under the low ground temperatures in the Arctic tundra are now slowly decomposing. In fact, the sub-seafloor under the Arctic Shelf is arguably undergoing the most dramatic warming on Earth. This warming is primarily associated with the rise of sea level at the end of the last ice age, when relatively warm Arctic Ocean water over -1.8°C (29°F) flooded over the much colder permafrost and gas-hydrate-bearing sediments less than -12°C (10°F) found beneath the coastal plain.

As the gas hydrate and permafrost layers degrade, unique subsurface processes occur. The decomposition of gas hydrate at depth can liberate substantial volumes of gas, weaken the sediments, and form gas pockets at depth. Similarly, thawing permafrost will weaken the sediments and liberate trapped gas bubbles. These changes can result in failures of the seafloor, especially along the steep slopes on the edge of the continental shelf and where pressurized gas may stimulate eruptions. Some researchers have voiced concern that increased gas releases into the atmosphere from the thawing sediments in the Arctic might result in a positive feedback, exacerbating other global warming trends. Understanding the connection between deep subsurface processes, sediment processes near the seafloor, and gas flux into the ocean and atmosphere is particularly important to assessing hazards and environmental conditions.

During this expedition, ROV dives were conducted in two different regions of the Beaufort Sea where existing data indicated possible gas plumes emanating from the seabed. One is a widespread area near the shelf edge in 80- to 120-meter water depth and the other a mid-shelf site (approximately 60 meters deep).

Gas venting from the seafloor in both areas was observed with the ROV's video cameras (Figure 26). Small amounts of gas could be seen venting over a widespread area near the shelf edge. Conversely, vigorous gas vented from a focused vent at the mid-shelf site, suggesting gas releases from over-pressured strata at depth were occurring. Video images of the seafloor and pre-existing high-resolution multibeam surveys show unusual, rounded seafloor textures near the shelf edge. These textures appear to occur in areas of erosion near the shelf edge; they may be associated with exposure of previously ice-bound permafrost sediments. The numerous white patches observed are presumed to be bacterial mats supported by methane.

Samples of the venting gases were collected using a novel tool fabricated for this expedition and mounted on the ROV. Subsequent laboratory measurements showed that the venting gas from both areas is predominantly composed of methane and the escaping gas may be liberated from decomposing permafrost or gas hydrate deposits that have been isolated from the sub-surface since the late Pleistocene, more than 12,000 years before present. Paull and his team are evaluating the concept that the fine-scale seafloor topography observed near the shelf edge and the widespread occurrence of diffuse gas venting in the same region are both related to the decomposition of permafrost.

Arctic Seafloor Expedition

Project lead/manager: Charles Paull
Project team: Larry Bird, Dale Graves, Alana Sherman, William Ussler
Collaborator: Scott Dallimore, Geological Survey of Canada, Sidney, British Columbia

Weird and Wonderful

Discovering new species, unfamiliar animal behaviors, and previously unrevealed interactions between species are some of the benefits of the regular presence of ships and researchers at sea. Some discoveries are the result of methodical close examinations of samples or specific areas; others are serendipitous. They all remind us of how little we know about our own "backyard".

Newly discovered group of algae live in both freshwater and the ocean

The smallest of the recently discovered organisms is a previously unknown group of algae found living in a wide variety of marine and freshwater environments. The DNA of this group of algae, which researchers dubbed "rappemonads", is distinctly different from that of other known algae. In fact, humans and mushrooms appear to be more closely related to each other than rappemonads are to some other common algae (such as green algae). Based on DNA analysis, the researchers believe that they have discovered not just a new species or genus, but a potentially large and novel group of microorganisms (Figure 27).

MBARI researchers Sebastian Sudek, Heather Wilcox, and Alexandra Worden, along with collaborators at Dalhousie University and the Natural History Museum (NHM) in London, discovered these microscopic algae by following up on an unexpected DNA sequence listed in a research paper from the late 1990s. Using DNA "probes" designed to detect the unusual DNA sequence, the researchers analyzed samples Worden's group collected from the Northeast Pacific, the North Atlantic, the Sargasso Sea, and the

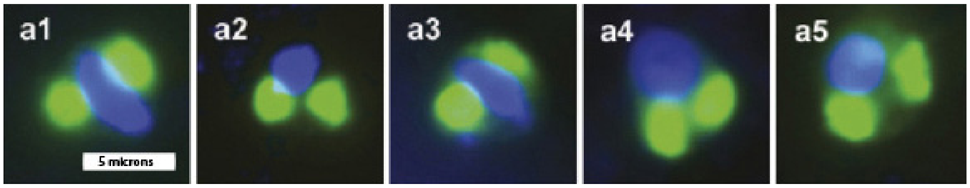


Figure 27: Researchers using novel molecular probes discovered an entirely new group of algae with unusual DNA sequences occurring in ocean and freshwater samples. Putting a name to a face, they called these microbes "rappemonads." This photomicrograph of rappemonads shows at least two chloroplasts (green dots) and a nucleus (blue dots) in each cell.

Florida Straits, as well as samples collected by the NHM group from freshwater sites. To the team's surprise, evidence of microscopic organisms containing the unusual DNA sequence was present in many of the samples.

To learn about the physical characteristics of the rappemonads, fluorescent compounds were attached to the newly developed DNA probes, then the probes were applied to intact algal cells. This caused parts of the rappemonads to glow with a greenish light, allowing the researchers to see individual rappemonads under a microscope. The greenish glow highlighted the rappemonad's chloroplasts, which contained DNA tagged by the probes. Chloroplasts are organelles inside plant and algal cells used in photosynthesis.

Rappemonads were found in a wide range of habitats, in both fresh and salt water, and at temperatures ranging from 52 degrees to 79 degrees Fahrenheit. Based on the evidence so far, the team believes rappemonads are likely to be found throughout much of the world ocean. Although apparently widespread, the algae may have escaped notice until now partly because researchers who study bigger phytoplankton such as diatoms would not observe them and they may be "filtered out" by researchers who study very tiny algae known as picoplankton.

Marine algae are key players in biogeochemical cycles, taking up carbon dioxide from the atmosphere and releasing oxygen. Worden and her group study marine algae in the context of their environment to gain an understanding of how rappemonads and other microorganisms affect large-scale processes in the ocean and in the atmosphere. A true census of marine algae and an understanding of how each group thrives are key components for modeling global biogeochemical cycles. Such models are essential for predicting how climate change will impact life on earth.

Submarine canyons provide mixed blessing for seafloor life

With dimensions comparable to the Grand Canyon, it's no surprise that Monterey Canyon harbors a variety of seafloor habitats. And even on the flat, muddy floor of the canyon, animal communities vary considerably. MBARI benthic ecologist Jim Barry and his former postdoctoral fellow Craig McClain analyzed the numbers and types of tiny animals (0.25 to 25 millimeters in size) living in the sediment deep in Monterey Canyon. Within 15 to 30 meters of the canyon walls, they found just a few species of animals in the sediment, and these animals were relatively small. Farther from the canyon walls, the researchers found a greater variety of animals and a greater total amount of living matter (biomass) in the sediment (Figure 28).

This discovery was surprising because organic material falling down from the canyon walls should provide more food for seafloor animals near the edges of the canyon. However, the researchers also noted that large, mobile animals, such as sea stars and sea cucumbers, were almost twice as common near the canyon walls as in the middle of the canyon. McClain and Barry speculate that the large mobile animals were able to take advantage of the abundant food supply near the canyon walls. By eating up all the extra food and disturbing the sediment, the larger animals apparently made it harder for a diverse community of tiny animals to evolve in the seafloor near the canyon walls.

Figure 28: Some of the tiny animals that live in the mud of Monterey Canyon. These animals include miniature snails, worms, clams, and crustaceans.

Jellies eating jellies

The fried-egg jellyfish, *Phacellophora camtschatica*, is a large, cold-water species that plays a role in the midwater gelatinous food web; it feeds principally on other gelatinous animals. The food web of gelatinous animals is an important component of pelagic ecosystems worldwide. Only recently has its significance as a major global repository of organic carbon been recognized. MBARI midwater ecologist Bruce Robison provided descriptions of jellies-who-eat-jellies-who-eat-jellies, and the implications of this food web for understanding carbon flux in the ocean.

Because most of its prey are not strong swimmers, *Phacellophora's* stinging cells (nematocysts) are mild. This means that other species, like fish, shrimp, and larval crabs can safely swim among its tentacles, where they find food and shelter from other predators. Among this jelly's common symbionts throughout the eastern North Pacific is the medusafish *Icichthys lockingtoni* (Figure 29). One of the strangest associations seen by MBARI scientists was a colony of goose-neck barnacles, which usually attach to flotsam at the surface, riding the bell of a fried-egg jelly hundreds of meters down into deep water.

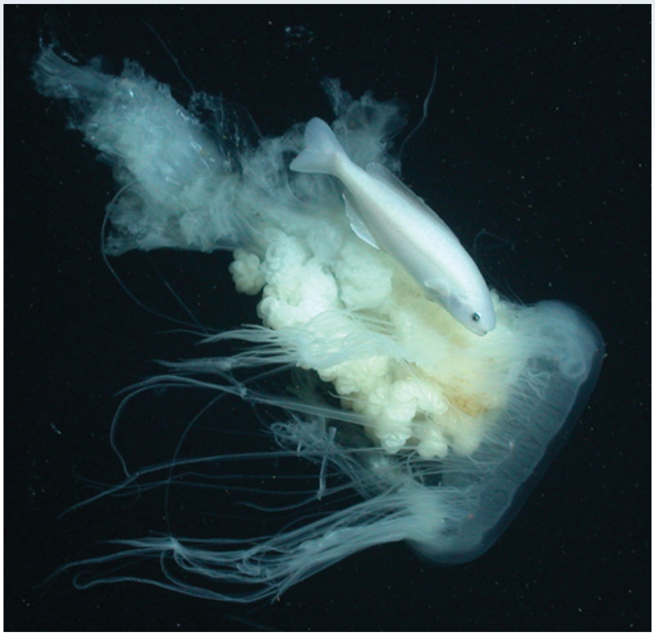


Figure 29: A medusafish finds shelter near this fried-egg jelly.

Spotting a rare sea toad

The rare sea toad, *Chaunacops coloratus*, is a strange fish with a balloon-shaped body, skin covered with small spine-like scales, and a large mouth. Like all angler fish, its first dorsal spine has been modified into a lure. The lure fits into a cavity on the snout seen as a white patch between the eyes (Figure 30). They "walk" across the seafloor using their stout pectoral fins or wedge themselves into rock crevices where ROV cameras have revealed them "fishing" with their lure.

Figure 30: This sea toad was observed at a depth of 3,300 meters on Taney Seamount.

MBARI researchers observed six sea toads during the August 2010 Taney Seamount expedition. In addition to photo-documenting the fish in situ, a specimen was captured; DNA analysis of the specimen has been completed, a first for this species. *C. coloratus* was originally described from a single specimen collected on the Cocos Ridge off Costa Rica. Previous to the Taney Seamount expedition, only a single observation of the species had been recorded in the 22 years MBARI has been exploring the deep sea. That initial observation was made during the 2002 Davidson Seamount expedition. Using the information gained from the Taney Seamounts, researchers plan to describe observed behaviors of the sea toad and its geographic and depth distribution, and determine its relation to other species in the strange-looking family Chaunacidae.

The longest brooding period

A rock rests on the seafloor far below the site where MBARI's Midwater Ecology team conducts its time-series measurements. Years ago when the team first explored the water column and the adjacent benthic region, they noticed that deep-sea octopus females were using this isolated rock as a site to brood their eggs. In general an octopus mother breeds just once, lays her eggs, and never leaves them until they hatch. She doesn't feed but she continually cleans and aerates the eggs while she guards them. For shallow-water species, the brooding period can last up to three months, and when her job is done, the mother dies.

But researchers know very little about the life span and brooding behavior of deep octopus species. Because the pace of life in cold, deep water is often slower than at shallow depths some have speculated that brooding might be considerably longer there. However, no such measurements have ever been made.

Nearly four years ago the midwater team visited the rock with the ROV and saw a plump-looking adult moving slowly toward the rock. When the team returned a few days later, the octopus was up on the rock, and had begun gluing her individual egg cases to the rock face. The team realized that they had witnessed an important event, but more significantly, they had a time-marker they could use to measure the brooding period.

Subsequently, whenever they could squeeze a little extra time out of a dive, the team visited the brooding mother. Although many months elapsed between visits, they knew they were observing the same female because of distinctive scars on her arms and pigment patches on her mantle. Between visits, the developing eggs showed slow but steady growth (Figure 31).

The story isn't over yet. When the team last visited the mother octopus in February of 2011, the eyes and suckered arms of her moving babies were visible in the egg cases, a sign that the eggs would soon hatch.

Aside from providing hard numbers on the brooding period for this species of octopus, these measurements will also give researchers a measure of the rates of physiological and developmental processes in the deep sea, data that have been impossible to acquire before. The recorded length of this brooding period has already surpassed that known for any other animal.

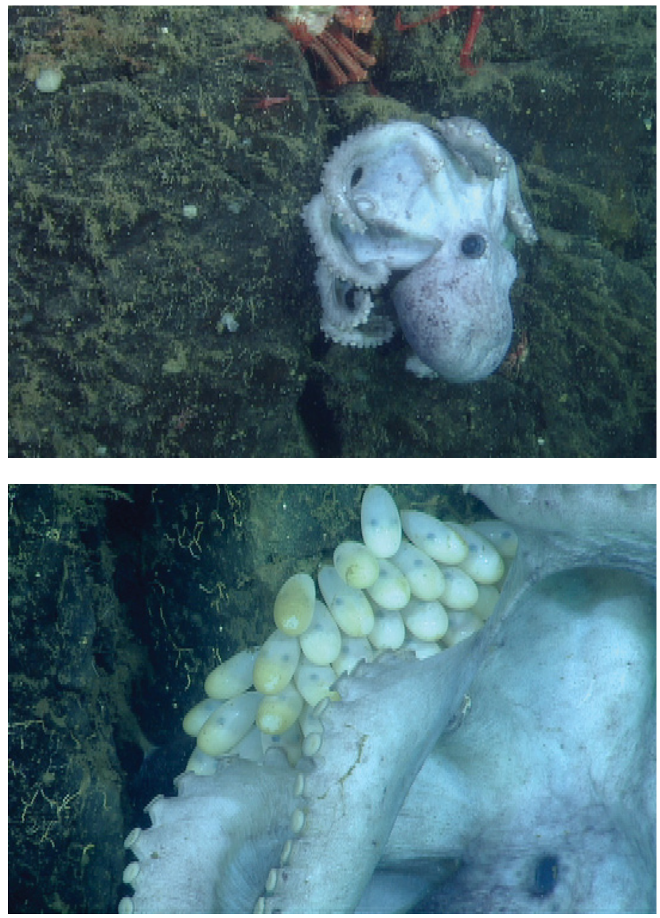


Figure 31: Above, the octopus has been on this rock for more than three years. Below, the eyes of the octopus babies are visible inside the oval egg cases, which are closely guarded by the mother.

On the Horizon

When limited resources constrain progress in research and development efforts, MBARI's reach is extended through external grants and collaborations. As an active participant in the work of the Center for Ocean Solutions (COS), MBARI is expanding the scope of its involvement in new ventures and the use of its technology. COS—a joint effort between MBARI, the Monterey Bay Aquarium, and Stanford University—is bringing together local groups and researchers to tackle important issues, such as climate change, ocean acidification, and hypoxia. MBARI's new strategic alliance with the nascent Schmidt Ocean Institute also creates new opportunities, such as access to ships far from the West Coast. These are a few examples of the connections and collaborations that enhance the institute's research and development program.

Climate change and ocean acidification

As the increase in global greenhouse gases leads to increased acidification of the ocean, MBARI is poised to study and address these issues on several fronts. Collaborations through the Center for Ocean Solutions enable experiments on the science of ocean acidification, a broad multi-institutional effort will study acidification impacts along the coasts of California and Oregon, and an international conference will bring together experts in Monterey.

Environmental change and ocean predators

A working group established by COS is charged with the preliminary analysis of ocean climate data and data from the Tagging of Pacific Predators (TOPP) program. One goal is to characterize the environment that sharks, tuna, and other ocean predators inhabit and the impacts that climate change will have on that environment and, consequently, the animals and their distribution. The second goal will be to use the knowledge gained to enact conservation measures and monitoring practices to preserve healthy populations of ocean predators. The working group includes members of MBARI, Stanford, and NOAA.

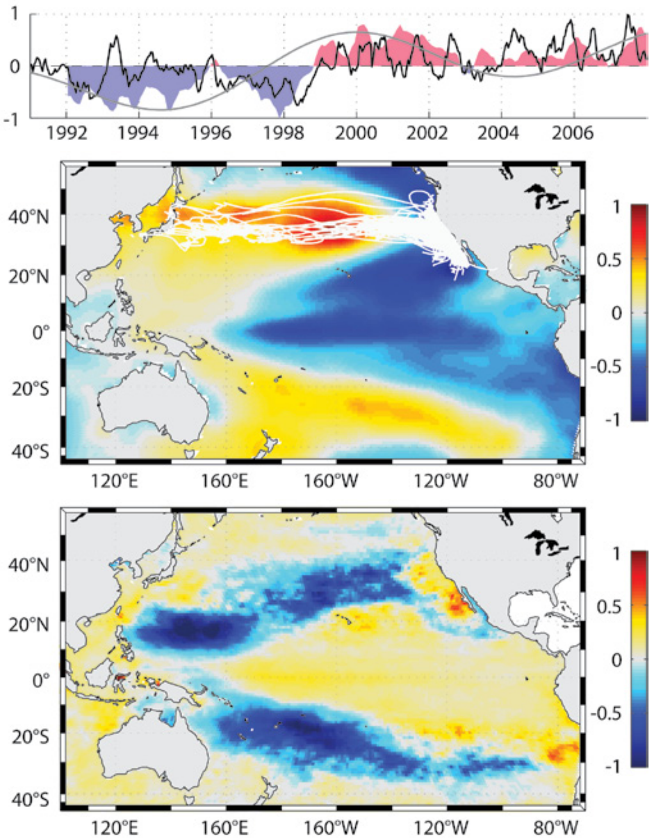


Figure 32: Bluefin tuna spend their lives migrating between the California Current and the coastal waters off Japan (white lines in the middle panel). These two regions are highly variable on interannual and multidecadal timescales. The two maps display the patterns of variability in sea surface temperature (SST, middle) and chlorophyll (bottom) The top panel shows the time variations of this variability (SST gray line; chlorophyll shaded colors) with chlorophyll measured in Monterey Bay (black line). The time series and the maps show that after 1998 the Pacific Ocean has displayed a large triangular area of cooler SST (blue) and higher chlorophyll (yellow) implying that in recent decades the California Current has been favorable for the bluefin tuna.

The TOPP program uses electronic tagging to observe the movements and migrations of animals in relation to ocean processes across a range of ecological scales with 4,300 tags on 23 species in the North Pacific and Atlantic basins. In the Pacific, the data include observations of sharks, pelagic fishes, cetaceans, turtles, pinnipeds, and seabirds. Complementing these data are global and regional data sets and models of the pelagic marine predators' habitat. These data should allow for the development of predictive relationships between the predators' activities and changes in their environment (Figure 32). Satellite and in situ observations show strong correlation in the variability of winds, sea-surface temperature, sea level, and chlorophyll. The working group proposes to establish linkages between the environmental changes and the distribution of marine predators. The researchers seek to develop better predictive models that can be used to protect these animals across the Pacific, particularly in the California Current Large Marine Ecosystem. The design of protected areas in pelagic habitats requires scientific information on the seasonal, decadal, and climate variation of animals, their movements, and the environment. Exploring how these changes impact populations using the enormous data sets already available will inform how best to design large-scale pelagic reserves and the monitoring systems necessary to validate the effectiveness of this approach.

Adapting deep-water technology to study climate change in the shallows

In a second collaboration under the auspices of the Center for Ocean Solutions, MBARI and Hopkins Marine Station (HMS) are developing a shallow-water version of the Free Ocean Carbon Dioxide Enrichment (FOCE) experiment for possible deployment on a new cabled observatory near Monterey. The new HMS Marine Life Observatory is designed to gather data for a scientific baseline on which to evaluate the health of the local marine ecosystem. The observatory is funded through the Center for Ocean Solutions and Stanford University.

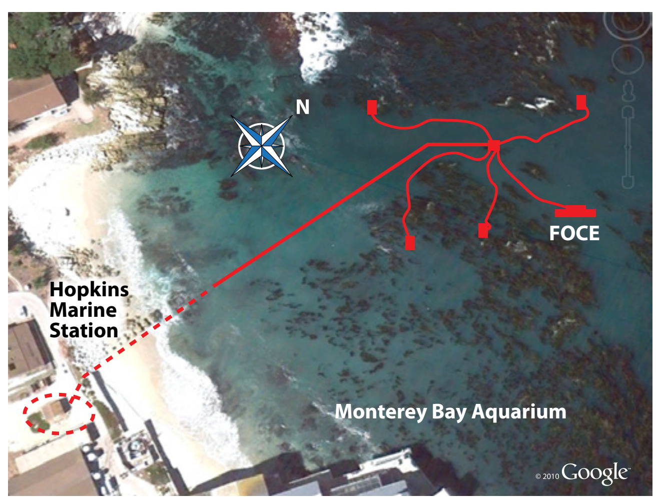


Figure 33: The proposed shallow-water FOCE will be one of five science instruments on the planned Hopkins Marine Station Marine Life Observatory, just offshore from the marine station in Pacific Grove, California.

Figure 34: The FOCE system planned for the new cabled observatory will be similar to this one installed offshore of Heron Island on the Great Barrier Reef in Australia.

This observatory will consist of a cable extending from shore to a 15-meter-deep site approximately 250 meters offshore (Figure 33). The planned location of the node would allow the placement of sub-nodes in a variety of nearshore habitats. Instruments on the system will provide real-time data on velocity, temperature, waves, transmissivity, dissolved oxygen, salinity, and pH from within a kelp-forest, along with simultaneous video of local fish populations.

MBARI's existing deep-water FOCE system was designed to test the impacts of increased CO_2 in the deep ocean within a closed system. Scientists can adjust the amount of CO_2 in the seawater flowing through a long flume to regulate the pH of the seawater inside the flume and examine the impacts on marine life. The shallow-water FOCE system to be deployed on the new observatory will use the well-established protocols and software architecture already in place on the existing FOCE system deployed on MBARI's own cabled observatory, the Monterey Accelerated Research System (MARS). MBARI software infrastructure and applications for ocean observing systems will transmit data to a shore-side data system via the Internet.

Because seafloor habitats often experience both unidirectional and oscillatory flows, this variable flow must be replicated by the FOCE system. For the shallow Monterey Bay site, unidirectional flows are typically 10 centimeters per second and oscillatory flows 30 centimeters per second. The flume chamber will be operable in two modes: as a once-through system like the FOCE systems deployed on the MARS cable and on a coral reef at Heron Island, Australia, (Figure 34) or as a closed, recirculating system that can be periodically replenished with additional seawater. The closed operation allows for greatly reduced CO_2 use and for the measurement of various parameters, such as net primary production and nutrient uptake. In addition, the lighting inside the chamber is designed to be as close to natural conditions as possible. A prototype of the shallow FOCE chamber will be built and then tested in Stanford's Environmental Fluid Mechanics Laboratory, where flow inside the chamber will be measured using dye injection to visualize any secondary flows.

The FOCE team, led by MBARI engineer Bill Kirkwood, is working with Stanford's Brock Woodson, who is responsible for installing the cable system. By the end of 2010, the FOCE system design process was under way and key components had been acquired. The cable was purchased and tested jointly with Stanford and plans were made for a shore station for the cabled observatory next to an existing landfall pipe.

Acclimation and adaptation to ocean acidification in the large California Current ecosystem

The increased acidification of the California Current due to the burning of fossil fuels (Figure 35), has led a broad coalition of researchers to study how ecologically important coastal invertebrates of this region respond to the observed changes in seawater chemistry. MBARI research in Monterey Bay demonstrated that the same increases in carbon dioxide and decreases in pH observed at the surface of the open ocean could be elucidated in a coastal upwelling environment, despite the large variability introduced by upwelling processes. How do these trends impact key nearshore ecosystem components? In a far-reaching collaboration with scientists from California and Oregon, MBARI researchers are contributing to the study of the impacts of ocean acidification on intertidal mussels and sea urchins. MBARI-developed instruments will be deployed in intertidal environments with divergent upwelling settings and hence pH differences (Figure 36). Intertidal ecologists, many of whom are involved in the Partnership for Interdisciplinary Studies of the Coastal Oceans (PISCO), will carry out in situ experiments and use the collected pH measurements to set up laboratory experiments that mimic the observed extremes in the environment. The results will be used to develop scenarios to better inform coastal management.

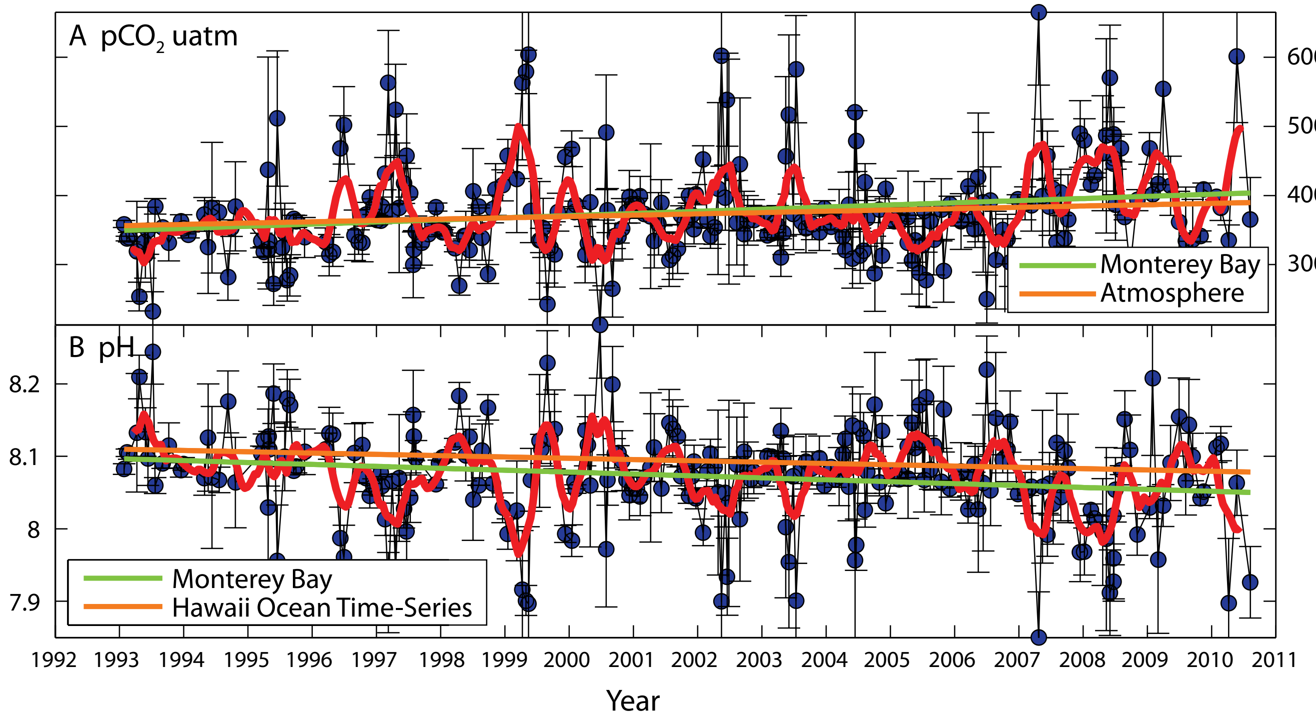


Figure 35: Sea surface partial pressure of carbon dioxide (pCO_2) has been measured during Monterey Bay Time Series cruises since 1993 (blue dots, upper panel). In spite of considerable seasonal and coastal variability (red lines), pCO_2 and acidity (blue dots, lower panel) both increase over the decades (green lines, greater acidity, decreasing pH) as a result of the ocean's absorption of CO_2 from the atmosphere. These increases are in the same direction but stronger than increases observed in the atmosphere and in the open ocean near Hawaii (orange lines); the stronger increases are presumably driven by recent multi-decadal cooling.

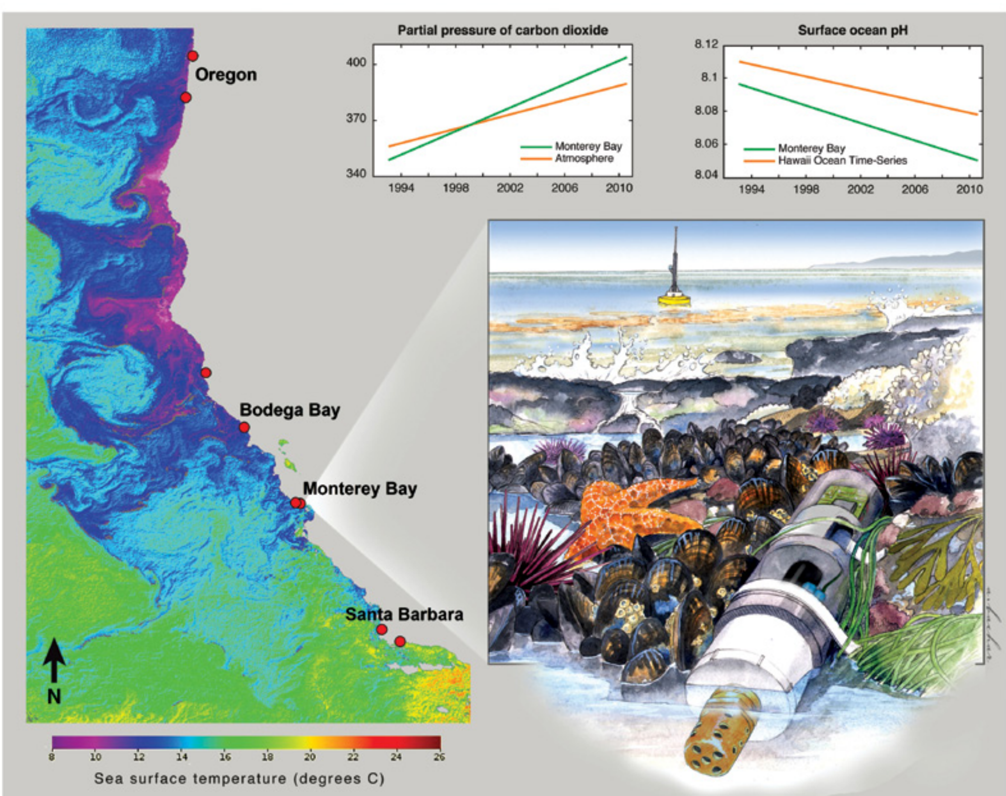


Figure 36. Leveraging off MBARI's pCO_2 and pH time-series data (see Figure 35, above), the National Science Foundation has funded scientists from Oregon State University, University of California (Davis, Santa Cruz, and Santa Barbara campuses), and MBARI to use MBARI intertidal pH sensors at eight sites along the North American West Coast to document near-surface ocean acidity. CO_2 and pH changes have already been detected in the atmosphere, in Monterey Bay, and off Hawaii (upper insets) and the new pH data will be associated with effects on important coastal invertebrates of the California Current Large Marine Ecosystem (lower inset).

Bringing together experts on the ocean in a high-CO_2 world

MBARI is recognized worldwide as a leader in advanced techniques for research on increasing carbon dioxide in the ocean and the related impacts on marine communities. MBARI's work, coupled with complementary research at neighboring institutions, established Monterey as an attractive location for the Third Symposium on the Ocean in a High-CO_2 World, scheduled for September 2012. The meeting is sponsored by the Scientific Committee on Oceanic Research, the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization (UNESCO), and the International Geosphere-Biosphere Programme, which together selected Monterey from eight bids to host the meeting.

The symposium is expected to attract more than 300 of the world's leading scientists in the field of ocean acidification to discuss the consequences of this phenomenon on marine organisms, ecosystems, and biogeochemical cycles. The meeting will also explore socio-economic consequences of ocean acidification, including policy and resource management implications. The symposium will build on the successes of the Paris and Monaco symposia in 2004 and 2008, respectively. The Paris meeting established the magnitude of ocean acidification for marine ecosystems and the Monaco symposium, which focused on the effects of acidification on marine organisms, resulted in a summary of the related policy issues.

Three MBARI researchers are helping to plan for this important meeting—Jim Barry is heading the local science planning committee, Peter Brewer is on the international planning committee, and George Matsumoto is chairing the local organizing committee. The effort is also supported by a consortium of regional research and educational institutions.

Welcoming a new player in the ocean sciences

Sharing expertise and gaining access to resources and ship time outside of Monterey Bay have already proven beneficial for both MBARI and the institute's newest strategic collaborators, the Schmidt Ocean Institute and its affiliated Marine Science and Technology Foundation (MSTF). Schmidt Ocean is dedicated to advancing scientific understanding of the global ocean. MBARI's Director of Marine Operations Steve Etchemendy, as well as MBARI scientists and staff, provided advice to the MSTF on the outfitting of its two new vessels for scientific work and on communications and data policies to help the two new organizations move ahead. MBARI served as host for a Schmidt Ocean Institute postdoctoral fellow and MSTF is leasing MBARI's research vessel *Point Lobos*.

MBARI researchers were selected to participate in the maiden research cruise of the Schmidt Ocean Institute ship, the *Lone Ranger*, enabling research projects in the North Atlantic basin, a part of the world not accessible with MBARI's own ships. For ecologist Ken Smith, the expedition provided an opportunity for comparative research on the *Sargassum* biological community, which he studied more than 30 years ago. MSTF also commissioned a deep-sea observatory developed by Smith and engineer Alana Sherman. The observatory was set up early in 2011 on the seafloor near the Bahamas to monitor the impact of climate change on the deep sea (Figure 37). This new station will allow comparisons to an existing research station in the Pacific from which Smith has collected a long-term time series on the transport of carbon from the surface to the deep sea.

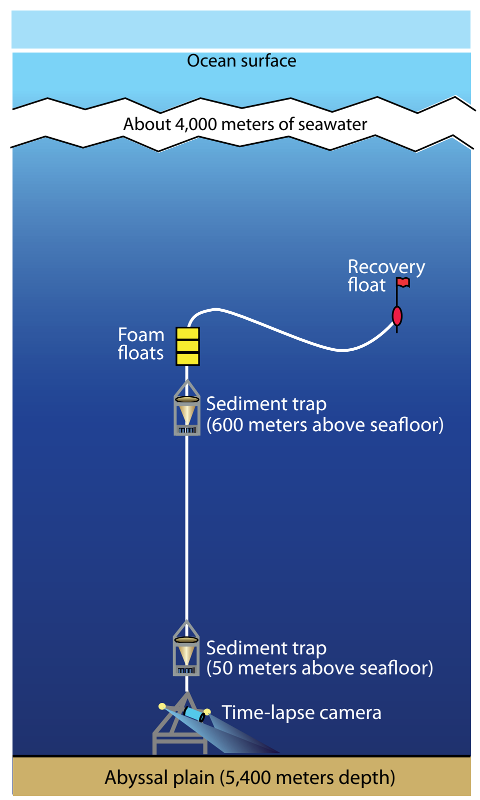


Figure 37: This simplified diagram shows key components of the deep-sea observing system to be installed at the southernmost sampling station of the Schmidt Ocean Institute Sargasso Sea cruise.

Behind the Scenes: Maximizing Sea Time Despite the Challenges

It goes without saying that MBARI's marine assets are crucial to the success of our research and engineering efforts and keeping the ships, moorings, and vehicles at sea is no small task. Life in the logistics arm of the Division of Marine Operations (DMO) is a constant juggle of addressing science and engineering needs, crew availability, mechanical and weather challenges, and navigating a maze of permits to maximize productive time at sea.

Each year under Director Steve Etchemendy's leadership, the division produces ship schedules for all three MBARI vessels, allocating the ship days awarded to scientists, engineers, and multidisciplinary expeditions that range along the Pacific coast from Canada to Mexico. Deputy Director of Marine Operations Chris Grech and Logistics Support Specialist Teresa Cardoza manage the changes, keeping track of every detail to make sure the ships, vehicles, and crew are ready so that each mission will be successful (Figure 38).

Throughout the year, numerous revisions are made to the schedules to adjust for changing science and engineering needs, weather, maintenance, and the occasional mechanical failure on a vessel or a remotely operated or autonomous vehicle. The flexibility of MBARI's ship scheduling is a unique advantage for both science and engineering development. Often planned science missions are dependent on instruments under development. If there is a setback in the design or building of an instrument, requiring a little more time in

Figure 38: Teresa Cardoza and Chris Grech study nautical charts to plan the optimal routing and scheduling to accommodate each research team's specific mission.

the lab before deployment, a quick schedule shuffle will be made. The Benthic Rover, the Free Ocean Carbon Dioxide Enrichment system, the Deep Environmental Sample Processor, and many other devices have all had such setbacks before their successful deployments at sea. Conversely, sea days lost to bad weather or an ROV or AUV malfunction can be made up by keeping the schedule flexible and by reserving a few contingency days each year.

While ship schedules are revised numerous times every year, 2010 proved to be an exceptional year of challenges and changes for Marine Operations. There were so many major adjustments that the schedule was completely revised 21 times.

Dramatic changes in ship operations

The year began with dramatic reductions in staffing and scheduled sea days on the R/V *Point Lobos* as a result of budget cuts. Additional sea days were added to the R/V *Western Flyer* and *Western Flyer* staffing was increased 25 percent to absorb some of the impact from the planned April lay up of the R/V *Point Lobos*.

In May, the Marine Science Technology Foundation (MSTF), an affiliate of the Schmidt Ocean Institute, asked to lease the *Point Lobos* for sea trials of a mapping AUV which was under development. An agreement between MBARI and MSTF arranged for a six-month use of the ship, beginning in August.

Then mechanical failures began to plague the R/V *Western Flyer*. One of the main 12-cylinder engines required a top-end rebuild, resulting in an unplanned, monthlong, shore-side maintenance period. And along with the new ROV *Doc Ricketts* came new problems causing several tether failures throughout the year. To compensate for lost sea time while the ship and tether were repaired, a number of days were transferred back to the *Point Lobos*. By year end the *Point Lobos* had completed an extra 70 sea days to support MBARI and MSTF research and development plans.

Balancing plans and resources

In-house communication, cooperation, and flexibility are paramount to handling these dramatic operational changes. Each time a sea day is changed from one ship and ROV system to the other, it sets in motion the rescheduling of a number of employees—the ships' crew and the ROV pilots or AUV team. The change often requires some modification in the equipment or science mission as each ship and ROV differs in its capabilities and configuration (Figure 39). Most of the ships' crew and ROV pilots are cross-trained on MBARI's vessels and vehicles. If needed, trained shore-based staff will go to sea, or the division makes use of external relief rolls to call in temporary crew.

Figure 39: ROV pilot Randy Prickett prepares a toolsled to be lifted onto the R/V *Western Flyer*, so that it can be attached to the ROV *Doc Ricketts* for midwater respiration experiments.

With the right tools and crew, the logistics staff can adapt to needs by transferring operations to another vessel. An extremely cooperative relationship between the Marine Operations and the Research and Development Divisions is critical to making these changes work for all involved.

Timely logistics for the Gulf of Mexico oil spill

Unplanned events far and wide can also upset the best-laid plans. In 2009, the mapping AUV was quickly packed up and sent off to dive on an active undersea volcano in Fiji. In 2010, the AUV technical group was called on to deploy to the Gulf of Mexico during the oil spill. MBARI was requested to immediately dispatch the upper-water-column AUV, equipped with gulper water samplers, to assist with determining the parameters of the spill.

The AUV was upgraded so that it could make dives as deep as 1,500 meters (previously it was designed to dive to 300 meters), packed, and shipped within three days of the first request for help in the Gulf of Mexico. Due to the value and sensitivity of the vehicle, DMO had to find truckers who were equipped and able to drive from Moss Landing, California, to Fouchon, Louisiana—nonstop. An additional flatbed truck loaded with support gear was also shipped. A week later, the AUV team was flown to the Gulf. Everyone pulled together working long hours and weekends to make the timeline.

Sending MBARI's AUV to the Gulf also meant that it was unavailable for local missions so the R/V *Zephyr* was docked and had to be rescheduled for non-AUV missions, such as mooring maintenance, equipment deployments, and recoveries. Once again scientists, engineers, and marine operations staff shifted their plans and projects because of this major change to the ship schedule.

Sending the ships far afield

All three MBARI vessels have conducted expeditions outside of Monterey Bay, though extended trips, such as to the Pacific Northwest and Gulf of California, usually involve the R/V *Western Flyer* and/or the R/V *Zephyr*. Having three vessels and two ROVs has given us the flexibility to conduct extended expeditions while continuing to explore and service instruments and experiments in Monterey Bay. Extended missions outside of Monterey Bay require months of planning. The logistics team must find a dock that can accommodate MBARI vessels and is located near the proposed dive sites. Services for trucking, storage, forklifts, fuel, food, water, lodging, and rental cars need to be arranged.

If one of our vessels will be entering foreign waters, a permit is required. Canadian and Mexican permits require months of advanced planning (Figure 40) and arranging for a collaborator from the host country to join the expedition. To date our vessels have docked as far north as Vancouver Island, British Columbia, and as far south as La Paz, Mexico, as well as west to Hawaii and a number of ports up and down the West Coast of the United States.

Forecasting the future and planning seagoing logistics to keep MBARI researchers, collaborators, and projects moving forward requires dedication and resolve. MBARI's Marine Operations team exemplifies excellence in logistical planning and flexibility.

Figure 40: Logistics Support Specialist Teresa Cardoza meets with a port agent in Pichilingue, Baja California Sur, Mexico, in preparation for the *Western Flyer's* 2001 expedition to the Gulf of California. Cardoza and Deputy Director of Marine Operations Chris Grech usually make reconnaissance visits to foreign ports where MBARI ships will be docking to arrange all the details in advance.

Project Summaries

Aquarium-MBARI Partnership

Project leads: Chris Harrold, George I. Matsumoto
Project manager: George I. Matsumoto
Project team: Nancy Barr, James Barry, Lori Chaney, Judith Connor, Kim Fulton-Bennett, Steven Haddock, Linda Kuhnz, Lonny Lundsten, Craig Okuda, Josh Plant, Kyra Schlining, Nancy Jacobsen Stout, Susan von Thun
Collaborators: Rita Bell, James Covel, Humberto Kam, Traci Reid, Kim Swan, and Jaci Tomulonis, Monterey Bay Aquarium, California

The Monterey Bay Aquarium and MBARI maintain various collaborative activities to support each other in achieving our respective missions. In 2010, the sister institutions worked on the remodel of the aquarium's Outer Bay Wing, including an exhibit on plankton. Both institutions investigated the potential educational use of live deep-sea video from the MARS observatory. Staff from both institutions contributed to the Conservation Action Fund, which provides small grants for local conservation efforts. MBARI staff again participated in the aquarium's Watsonville Area Teens Conserving Habitats program as mentors and as hosts for the annual high school students' presentations to the community. MBARI staff met regularly with the aquarium's communications staff and contributed lectures, video, and writing to aquarium programs and the *Shorelines* newsletter. In addition to all these activities, the aquarium and MBARI benefit from sharing expertise via trainings, seminars, classes, workshops, and outreach efforts.

Benthic Biology and Ecology

Project lead/manager: James Barry
Project team: Kurt Buck, Chris Lovera, Craig Okuda, Eric Pane, Josi Taylor, Patrick Whaling
Collaborators: Jason Hall-Spencer and Stephen Widdicombe, Plymouth Marine Laboratory, United Kingdom; Gretchen Hofmann, University of California, Santa Barbara; Taewon Kim, Hopkins Marine Station of Stanford University, Pacific Grove, California; Craig McClain, University of North Carolina, Durham

The team investigated the capacity of deep-sea animals to maintain or restore physiological processes under changing ocean conditions and future climate scenarios. Animals collected from field locations were studied in the laboratory under anticipated future ocean conditions. Those experiments complemented field studies of animal metabolism using a benthic respiration system; the system injects small quantities of carbon-dioxide-enriched or oxygen-rich seawater into chambers holding individual animals. This approach provided a basis for evaluating potential impacts on animal growth, survival, and reproduction. Development of best practices for this research will help the international research community. Jim Barry's contribution to a National Academies report on ocean acidification helped inform the world of the potential impacts of ocean acidification. Barry also served on the Surface Ocean Lower Atmosphere Study/Integrated Marine Biogeochemistry and Ecosystem Research Working Group 3 to coordinate international research on ocean acidification.

Benthic Event Detectors

Project leads: Charles Paull, Alana Sherman, William Ussler
Project manager: Brian Kieft

AUV mapping surveys, ROV vibracoring, and simple experiments have shown that Monterey Canyon is an active conduit for the movement of sediment from the nearshore environment to the deep sea. Previous experiments suggested that portions of the seafloor may slide down the canyon episodically in events capable of moving boulder-sized objects hundreds of meters. The benthic event detector will determine the magnitude, timing, and dynamics of sediment debris flow events in upper Monterey Canyon. In 2010, the project team developed the instrument concept design and focused on how to retrieve data acoustically from an instrument buried during a sediment flow event. The battery-powered instrument will be equipped with motion sensors to measure the onset, duration, and dynamics of sediment debris flows. Data captured by the instrument during flow events will allow geologists to distinguish which model best describes sediment movements down submarine canyons.

Engineers Brian Kieft and Alana Sherman control the benthic event detector from the beach.

Biodiversity Initiative

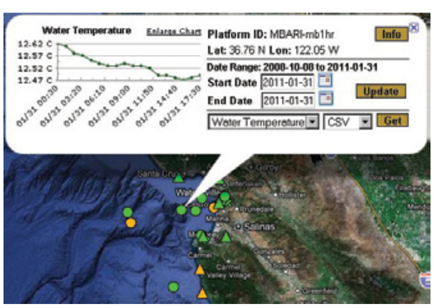
Project leads: Duane Edgington, Bruce Robison
Principal investigators: James Barry, Steven Haddock, Charles Paull, Bruce Robison, Ken Smith, Robert Vrijenhoek, Alexandra Z. Worden

Because biodiversity is constantly changing, the team working on this initiative has shifted its focus from building a biodiversity baseline to studying the dynamic aspects of change in the deep sea. The initiative seeks to find causal links between shifting patterns of biodiversity and pelagic and benthic habitat changes, due to natural and anthropogenic forces. In 2010, researchers used the video annotation database to investigate species distributions and changes in deep-sea biological communities. Analysis focused on identification of long- and short-term population changes in the midwater community and temporal changes at the Smooth Ridge benthic site. New tools were used to evaluate data quality. Software developers and technicians worked to improve and refine the tools, which are expected to provide customized quantitative and qualitative data sets that will allow researchers to begin to understand the spatial, environmental, and historical context of the data.

Central and Northern California Ocean Observing System (CeNCOOS)

Project leads: Francisco Chavez, Steve Ramp
Project manager: Heather Kerkering
Project team: Fred Bahr, Tom Wadsworth
Collaborators: Over 50 throughout California

In 2010, the White House Recommendations of the Interagency Ocean Policy Task Force provided the first national policy for the stewardship of the ocean, the Great Lakes, and our coasts. CeNCOOS and the other Integrated Ocean Observing System (IOOS) regional associations responded to the new policy by integrating their efforts. The CeNCOOS website serves as the primary interface for data from the regional observing network, consisting primarily of automated shore stations, coastal high-frequency radar stations, and ocean gliders. The team began work on oceanic and atmospheric modeling and prediction—critical elements of the observing system—and participated in the October CANON experiment. CeNCOOS co-hosted the first national product developer's workshop with participants from IOOS regional associations who viewed products and swapped code. The new CeNCOOS Data Portal allows the public and researchers to access data from the region. Work continues on adding additional stations and sensors and making the data portal accessible via mobile devices.



Data portal for the Central and Northern California Ocean Observing System.

Core Conductivity-Temperature-Depth (CTD) Data

Project lead: David Caress
Project manager: Mike Burczynski
Project team: Gernot Friederich, Mike McCann, Reiko Michisaki, Kim Reisenbichler, Bruce Robison, Richard Schramm

This project provides institutional support for the maintenance, operation, calibration, and configuration of the core conductivity, temperature, and depth (CTD) instruments on the ROVs, rosette profilers, and ships, as well as related electronics and related hardware. Development continued on the user interface for real-time ROV data display with numerous improvements. The CTD team continued validation of ROV oxygen sensor data; both ROVs are now outfitted with dual sensors for improved data quality.

Core Mooring Data

Project lead: David Caress
Project manager: Mike McCann
Project team: Fred Bahr, Francisco Chavez

Some MBARI mooring data (surface CTD, T-string, meteorological, GPS, ADCP, and pCO_2 data) have been designated as core data streams, which means that support for the collection, processing, and archiving of the data is provided on an institutional basis rather than through individual projects or divisional budgets. MBARI has archived data from moorings M1, M2, M3, and M4 since 1989. These data have been quality-controlled with bad and suspect records flagged. The flagging preserves all original data but provides an indicator of data quality. The data are stored in files on a shared drive making quality-controlled and derived data products available for users.

Core Navigation Data

Project lead/manager: David Caress
Project team: Knute Brekke, Mike Burczynski, Lori Chaney, T. Craig Dawe, Dale Graves, Linda Kuhnz, Eric Martin, Mike McCann, Eric Nelson, D.J. Osborne, Randy Prickett, Bryan Schaefer, Richard Schramm, Mark Talkovic

Navigation from MBARI research vessels *Point Lobos* and *Western Flyer* and from ROVs *Ventana*, *Tiburon*, and *Doc Ricketts* are collected, processed, and archived by team members from the Marine Operations, Engineering, and Information and Technology Dissemination Divisions. In 2010 the team oversaw the operation and maintenance of ROV and ship navigation hardware and provided maintenance and development of software for automated processing and archiving of ship and ROV navigation. They also edited ROV navigation and monitored data quality. The primary challenge was the poor quality of *Doc Ricketts* ultrashort baseline (USBL) navigation. The hardware and most of the software issues on the ship were addressed and the *Western Flyer's* USBL system was successfully calibrated in early 2011.

Development of an Autonomous Tissue Sampler

Project leads: Erika Raymond, Robert Vrijenhoek
Project manager: Erika Raymond
Project team: Larry Bird, David French, Michael Risi
Collaborator: Linda Park, Northwest Fisheries Science Center, Seattle, Washington

This new tool allows minimally invasive, non-lethal recovery of genetic material for the identification of fish species in remote locations. The system consists of a video camera linked to a tissue-sampling mechanism with event detection, infrared communication, a control system, and acoustic release. The sampler was successfully deployed four times in 2010. Off-the-shelf biopsy needles were investigated as a possible means of obtaining tissue samples. As a result of these initial tests, a spring-loaded shaft system was developed and will be tested.

Larry Bird works on construction of an automated system for sampling animal tissue in the deep sea.

Ecology and Dynamics of Picophytoeukaryotes

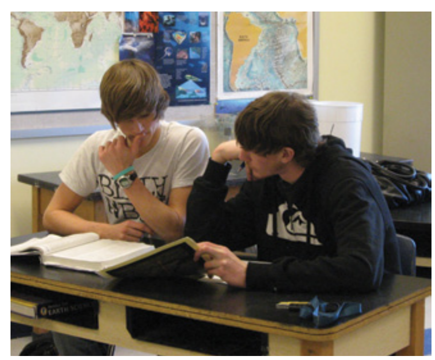
Project lead: Alexandra Z. Worden
Project managers: Sebastian Sudek, Alexandra Z. Worden
Project team: Tracy Campbell, Elif Demir-Hilton, Alyssa Gehman, Adam Monier, Melinda P. Simmons
Collaborators: Andrew Allen, J. Craig Venter Institute, San Diego, California; Francisco Chavez and Ken Johnson, MBARI; Marie Cuvelier, University of Miami, Florida; Connie Lovejoy, University of Laval, Quebec City, Canada; Matthew Sullivan, Arizona State University, Tempe; George Weinstock, Washington University in St. Louis, Missouri; Jon Zehr, University of California, Santa Cruz

The research team developed and published on new methods for targeted metagenomics. Their novel approach combined high-speed cell sorting by flow cytometry at sea with subsequent sequencing to generate and analyze partial genomes from uncultured eukaryotes. They quantified the abundance, biomass, and production rates of a broadly distributed uncultured group of marine phytoplankton. Another novel group of uncultured algae was also investigated in detail using newly developed molecular probes. Understanding of distributions of several "known" eukaryotic phytoplankton groups was further refined. Significant advances were also made in identifying potential indicator genes for biogeochemical cycling. This research team also participated in a community effort led by Adjunct Jon Zehr to develop common microarrays to explore the activity and distribution of marine microbes.

Education and Research: Testing Hypotheses (EARTH)

Project lead/manager: George I. Matsumoto
Collaborators: Ruth McDonald, Lincoln County School District, Oregon; Karen Wegner, National Science Foundation Science and Technology Center for Coastal Margin Observation and Prediction, Beaverton, Oregon

EARTH offers a unique workshop to enable teachers to integrate real-time data and tested curriculum in an interactive and engaging way. Recognizing the need to educate the public about scientific methodology and the value of research, MBARI developed EARTH to test new ideas for public outreach and education and disseminate MBARI research. This project aims to inspire the next generation of ocean advocates; it is one of the only teacher workshops that rewards educators (by being eligible to return for additional workshops) for incorporating the activities into their curricula. The 2010 EARTH workshop was co-hosted by the Center for Coastal Margin Observation and Prediction and the Oregon Coast Aquatic and Marine Science Partnership in Beaverton, Oregon. Teachers at the workshop learned about instruments used in ocean observatories, as well as how to use podcasts to share information.



High school students discuss an EARTH lesson plan.

Feasibility of a Digital Video Archive

Project leads: Charles Paull, Brian Schlining
Project manager: Nancy Jacobsen Stout
Project team: Lori Chaney, Danelle Cline, Duane Edgington, Dale Graves, Linda Kuhnz, Lonny Lundsten, Todd Ruston, Kyra Schlining, Susan von Thun, Todd Walsh

This feasibility study investigated requirements for transitioning MBARI's video archives from a tape-based system to a hard-disk-drive-based system. Serving video in a digital file format will enhance the accessibility and usability of the archives. Instantaneous access should improve video archive management, the efficiency of processing requests, and data analysis. Numerous digital video technologies, systems, and procedures were investigated, and an overall architectural plan was created. Various video compression formats (full resolution and lower resolution) were considered for their suitability for human- and machine-based analyses, potential audiences, and modes of transmission. The project team tested digital video software and hardware technologies, compression algorithms, processing hardware, backup procedures, and distribution methods. Best practices were refined for metadata and video rights management, configuration, annotation, and retrieval of digital video files to be compatible with the Video Annotation and Reference System (VARS) and related programs. This transition promises to advance long-term observational capabilities and methods for monitoring ocean health.

Feasibility of a RED ONE Camera for ROV Use

Project leads: Mark Chaffey, Steven Haddock
Project manager: Todd Walsh
Project team: Dave French, Lonny Lundsten

New digital 35-millimeter video technology is marked not only by greatly increased resolution of the image captured, but also by increased dynamic range, greater adjustment latitude in post-production, and higher frame rates. These advances can be used to better describe, identify, or discover new organisms. This project team worked to identify the camera systems which would best suit operation on MBARI ROVs.

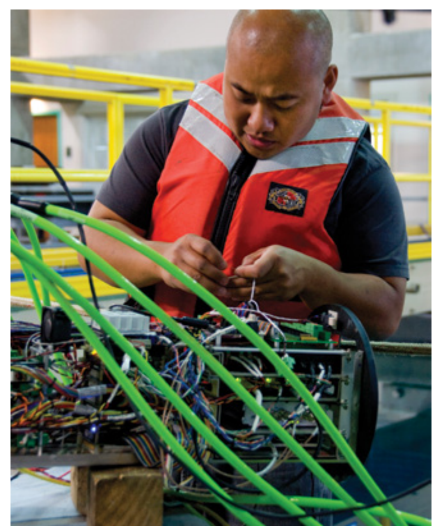
High-resolution close-up image of a larval form of a polychelid lobster taken with a new digital camera.

Comparative testing will be conducted using equipment from three leading manufacturers identified in the preliminary evaluation.

Free Ocean CO_2 Enrichment (FOCE)

Project leads: James Barry, Peter Brewer, William Kirkwood
Project manager: William Kirkwood
Project team: Kent Headley, Bob Herlien, Chad Kecy, Chris Lovera, Tom O'Reilly, Ed Peltzer, Karen Salamy, Jim Scholfield, Farley Shane, Peter Walz
Collaborators: Jean-Pierre Gattuso, Laboratoire d'Oceanographie de Villefranche, France; David Kline, University of Queensland, Australia; Stephen Monismith and Brock Woodson, Stanford University, California; Stephen Palumbi, Hopkins Marine Station of Stanford University, Pacific Grove, California; Stephen Widdicombe, Plymouth Marine Laboratory, United Kingdom

Essential elements developed for the FOCE included a CO_2 dissolution system for fluid delivery, a mixing chamber for creating the desired concentration of CO_2, a delay loop to allow time for equilibrium to be achieved, flooding of the experimental zone with the CO_2-enriched water, and observation of the geochemical and ecosystem changes induced. Most of the key elements were deployed on the MARS observatory for six months. The greatest challenge was the deployment of a pH sensing system. The long deployment of the pH sensors was successful and set a new record in pH performance. The pH sensors were fully operational and revealed a semi-diurnal tidally-driven pH change at the MARS site. The CO_2 enrichment test systems were also deployed. These simple boxes provided valuable data on dissolution rates at the depth and currents observed around the MARS site.



Jose Rosal assembles electronics for the Free Ocean CO_2 Enrichment system.

High-Resolution, Near-Surface Seismic Refraction Tomography

Project leads: David Caress, Rich Henthorn
Project manager: David Caress
Project team: Doug Conlin, Paul McGill, Hans Thomas, Duane Thompson

The goal of this project is to develop a high-resolution seismic refraction capability to image the shallow structure of the subsurface seafloor. A refraction experiment was planned and executed in which the chirp source consisted of the mapping AUV's chirp subbottom profiler; the receivers were hydrophone recording packages deployed from the R/V *Zephyr*. The experiment was conducted at the Santa Monica Basin gas seep mound. The team succeeded in deploying the hydrophones, executing mapping AUV missions running profiles at a 20-meter altitude over the instruments, and recovering the hydrophones with the recorded data. Unfortunately, as with previous experiments, the processed data showed no evidence of refracted arrivals. The team will continue to consider approaches to achieving the high-resolution refraction capability using on- or near-bottom sources and receivers.

Imaging Autonomous Underwater Vehicle (IAUV)

Project leads: James Barry, Brett Hobson, Ken Smith
Project manager: Brett Hobson
Project team: Danelle Cline, Lonny Lundsten, Tom Marion, Rob McEwen, Jim Scholfield, Farley Shane, Alana Sherman, Hans Thomas

The high-resolution, color, still-image capture capability for the *Dorado* AUV developed by this team will bridge the gap between the large-area bathymetric maps generated by MBARI's mapping AUV and the relatively small areas the ROVs explore. The IAUV can capture a continuous strip of images 4.5 meters wide and 18 kilometers long which can be assembled as small photo-mosaics. In 2010 the Marine Operations group used the IAUV to capture images along a long-term benthic time-series site in Monterey Bay that had traditionally been surveyed using the ROV *Ventana*. The team is improving the ability of the AUV to accurately maintain a three-meter altitude over progressively rougher terrain. This development effort will merge with a new ocean imaging project to develop a hovering AUV that can combine very high-resolution acoustic maps with three-dimensional stereo imagery.

Marine Metadata Interoperability (MMI)

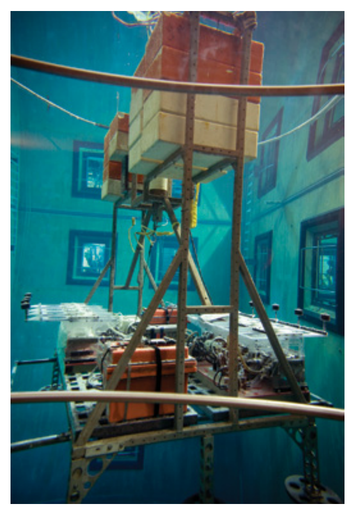
Project lead/manager: Carlos Rueda
Project team: Duane Edgington, Kristine Walz
Collaborators: Luis Bermudez, Open Geospatial Consortium, Washington, D.C.; Philip Bogden, Southeastern Universities Research Association, Washington, D.C.; Matthew Howard, Texas A&M University, Austin; Andy Maffei and Al Plueddemann, Woods Hole Oceanographic Institution, Massachusetts; Karen Stocks, University of California, San Diego

This project promotes the exchange, integration, and use of marine data through enhanced data publishing, discovery, documentation, and accessibility. The project team accomplished a major milestone in 2010 with the consolidation of the MMI ontology registry and repository and creation of a web portal where the ocean science community can document and manage technical vocabularies. In addition, the team completed the MMI device ontology which allows data managers to formally capture marine instrument descriptions and provenance metadata for oceanographic observations in an interoperable way. MMI's resources and advanced technologies gained significant visibility in the marine and geosciences communities. Various research groups are now implementing the approaches and deploying the tools that the MMI project has developed.

Modification of In Situ Respirometers for Ocean Acidification Studies

Project leads: James Barry, Kurt Buck, Kim Reisenbichler, Michael Risi, Bruce Robison
Project manager: Bob Herlien
Project team: Craig Okuda

MBARI's benthic and midwater respiration systems measure the metabolic rates and performance of animals under normal conditions as well as during manipulative experiments that simulate the effects of ocean acidification. The engineering design and implementation of the new respirometer system was completed in 2010. The new system required redesign of the chamber using oxygen-impermeable materials. A new toolsled for ROV *Doc Ricketts* facilitated convenient deployment of the midwater system. An improved software system for the respirometers now allows for more complex experiments. The benthic and midwater systems were each deployed several times during the year.



Trials of the benthic respirometer system in the MBARI test tank.

Molecular Ecology and Evolution

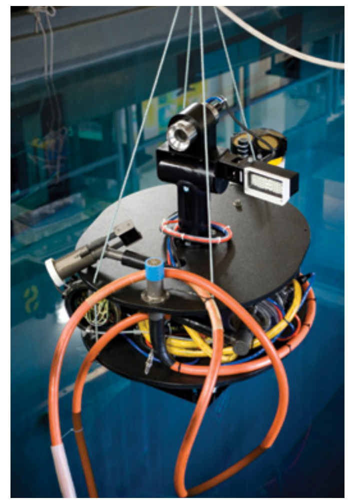
Project lead: Robert Vrijenhoek
Project manager: Shannon Johnson
Project team: Julio Harvey, Roman Marin III, John Ryan, Chris Scholin
Collaborators: Shawn Arellano, Woods Hole Oceanographic Institution, Massachusetts; Katharine Coykendall, U.S. Geological Survey, Kearneysville, West Virginia; Shana Goffredi, Occidental College, Los Angeles, California; Joe Jones, University of South Carolina, Columbia; Andrezj Kaim, Instytut Paleobiologii Warszawa, Poland; Yasunori Kano, University of Tokyo, Japan; Stephen Karl, University of Hawaii, Manoa; Ray Lee, Washington State University, Pullman; Crispin Little, Leeds University, United Kingdom; Richard Lutz, Rutgers University, Newark, New Jersey; Mary McGann, U.S. Geological Survey, Menlo Park, California; Victoria Orphan, California Institute of Technology, Pasadena; Greg Rouse and Nerida Wilson, Scripps Institution of Oceanography, La Jolla, California; Tom Schultz, Andrew Thaler, and Cindy van Dover, Duke University Marine Laboratory, Beaufort, North Carolina; Michel Segonzac, Institut Francais de Recherché pour l'Exploitation de la Mer, France; Ellen Strong, Smithsonian Institution, Washington D.C.; Shinji Tsuchida, Japan Agency for Marine-Earth Science and Technology; Anders Warén, Swedish National Museum, Stockholm; Chad Widmer, Monterey Bay Aquarium, California; Yong-Jin Won, Ewha Womans University, Seoul, South Korea; Craig Young, Oregon Institute of Marine Biology, Coos Bay; C. Rob Young, Massachusetts Institute of Technology, Cambridge

Knowledge of zooplankton diversity, distribution, and abundance is critical to understanding marine food webs and the effects of environmental change. The project team used molecular probes on water samples from the *Dorado* AUV and from the ESP to identify the diversity and abundance of native zooplankton species (larval barnacles, mussels, worms, crabs, and adult copepods) and alien species (such as the larvae of the invasive green crab). The simultaneous acquisition of the samples and environmental data revealed an increase in copepods with high chlorophyll concentrations along upwelling fronts. During the CANON experiment, water samples from the *Dorado* AUV were probed for zooplankton, harmful algae, bacteria, and toxins. The results were compared with traditional methods. Preliminary results include the first unequivocal records of polychaete worm larvae in surface waters of the northern bay detected by the ESP. This observation opens a window for assessing benthic-pelagic coupling. Studies focused on the invertebrate animals associated with whale carcasses in Monterey Bay continue.

Monterey Accelerated Research System (MARS)

Project lead: Steve Etchemendy
Project manager: T. Craig Dawe
Project team: Ken Heller

Several instruments were installed on the MARS cabled observatory and a third survey of the 52-kilometer cable was completed. MBARI researchers tested the Deep Environmental Sample Processor (D-ESP) and the Benthic Rover, Woods Hole Oceanographic Institution deployed an Acoustic Communications Base Station, scientists from NOAA/Oregon State University deployed a bottom pressure recorder and a precision tiltmeter (both designed to monitor inflation or deflation in submarine volcanic areas caused by magma movements underground), and Scripps Institution of Oceanography deployed an ocean-bottom seismometer to develop data management techniques for the national Ocean Observing Initiative. Programs and an exhibit at the Monterey Bay Aquarium provided MARS and the Ocean Observing Initiative with wide public exposure. Video images from MBARI's Photographic Benthic Observing System facilitated the deployment of new instruments on MARS and the images were made available at the aquarium and on the Internet. MBARI's EARTH teacher workshops also used MARS as a tool at over 20 presentations to students and educators.


A camera system developed for the MARS observatory before trials in the test tank.

Mooring Maintenance

Project leads: Francisco Chavez, Mike Kelley
Project manager: Mike Kelley
Project team: Paul Coenen, Dave French, Craig Okuda, Erich Rienecker, Rich Schramm
Collaborators: Curtis Collins, Naval Postgraduate School, Monterey, California; Mary Silver, University of California, Santa Cruz

MBARI moorings have provided 20 years of time-series observations and are considered model systems for the network of coastal observatories planned for U.S. coastal waters. A number of MBARI scientists as well as outside researchers use data from the moorings. The M1 mooring has been the platform for the development of the CO_2 analyzer and the longest time-series data set for a biogeochemical sensor in the surface waters. In addition to the M1 and M2 deployments, the M0 mooring was maintained for another year.

Mooring Technology Collaboration

Project lead: Andrew Hamilton
Project manager: Mark Chaffey
Collaborators: Yannick Aoustin, Institut Français de Recherché pour l'Exploitation de la Mer

Work began on the export of MBARI's Monterey Ocean Observing System (MOOS) mooring technology to the European ocean observatory community. The MBARI team is collaborating with the French Institute for the Exploitation of the Sea (IFREMER) to transfer knowledge and techniques for the design, modeling, and testing of mooring riser cables. A second element of the project is to design a new cable based on high modulus fibers that are more resistant to low-tension bending, as a way to increase the lifespan of the mooring cable from 18 to 36 months. Preliminary model results were produced and a preliminary report was sent to IFREMER. A sample cable of the planned material and construction has been purchased by MBARI and laboratory testing will take place in 2011.

MOOS Upper Canyon Experiment

Project leads: James Barry, Charles Paull
Project manager: Mark Chaffey
Project team: Larry Bird, John Ferreira, Kevin Gomes, Kent Headley, Mike Kelley, Brian Kieft, Chris Lovera, Ed Mellinger, Tom O'Reilly, Karen Salamy, William Ussler

A benthic cable was laid from the MOOS surface mooring to an instrument site in the center of the canyon. Before the instrumentation package was connected, a sediment transport event occurred in the upper canyon reducing visibility on the seafloor to less than one meter—the exact type of event the system is designed to measure. The installation was completed later. The system flawlessly collected high-speed data for three months until the anchor release tackle unexpectedly broke and the mooring went adrift. The mooring was quickly re-anchored and repaired for another 10 weeks of service until a second tackle failure occurred. The experiment was ended and the mooring was recovered. The project established that all of the major mooring electronic, communications, and data systems are fully mature, that heavy maintenance and repair operations could be undertaken while at sea, and that the shallow experiment site produced more stress on the anchor system than a deeper canyon site.

Observatory Middleware Framework

Project leads: Duane Edgington, Kevin Gomes
Project manager: Duane Edgington
Project team: Carlos Rueda
Collaborators: Randy Butler, Terry Fleury, and Von Welch, University of Illinois, Urbana-Champaign

The Observatory Middleware Framework enables the integration and configuration of instruments, data streams, processing, and storage into a customized observatory without concern for resource implementations. The team focused on performance evaluation of the OMF framework, to enable estimation of scalability of the system to large environmental sensing networks.

The Ocean in a High CO_2 World

Project leads: James Barry, Peter G. Brewer, William Kirkwood
Project manager: Edward Peltzer

This institute initiative unites the work of several MBARI groups assessing the future impacts of elevated oceanic carbon dioxide levels (and the concomitant lower pH) on marine ecosystems. Each lab is developing new systems and methods for a combination of field and laboratory studies, and addressing the associated social, economic, and permitting issues. The key components of this project are the Free Ocean CO_2 Enrichment (FOCE) development, field and laboratory studies evaluating responses (animal survival, metabolic rate, and reproduction) to elevated CO_2 levels and increased temperature, and field measurements and theoretical models of ocean chemistry and physical processes. The researchers continue to map the rapidly evolving and intertwined changes in oceanic temperature, oxygen, and carbon dioxide so that the results of local experiments can be extended to distant oceanic regions with reasonable predictions.

Outline Video Annotation

Project lead: David Caress
Project manager: Lonny Lundsten
Project team: Lori Chaney, Linda Kuhnz, Brian Schlining, Kyra Schlining, Nancy Jacobsen Stout, Susan von Thun

The Video Annotation and Reference System (VARS) database and the accompanying video archive, currently including over 18,000 hours of deep-sea observations, are the primary products of this project. The VARS database contains over three million observations and 4,451 unique concepts. The open-source VARS system software was set up at the Hawaii Undersea Research Laboratory (HURL), and is now in use there. The annotation team collaborated with other MBARI project teams to expand archiving and annotating functions to include still images and video files from other imaging systems. The video lab staff completed over 170 requests from both internal staff and external partners including fully edited video productions, still image and data requests for research use, VARS training, and tours for distinguished visitors.

Pelagic-Benthic Coupling and the Carbon Cycle

Project lead: Ken Smith
Project manager: Alana Sherman
Project team: Jake Ellena, Rich Henthorn, Brett Hobson, Paul McGill, Michael Vardaro, Stephanie Wilson
Collaborators: Dave Checkley, Scripps Institution of Oceanography, La Jolla, California; Jeffrey Drazen, University of Hawaii, Manoa; George Jackson, Texas A&M University, College Station; Henry Ruhl, University of Southampton, United Kingdom

In 2010, the Benthic Rover was deployed twice for a week each time at the long-term time-series site, Station M (depth 4,000 meters). The team collected data at that site for estimates of fresh material arriving on the seafloor and the response of the benthic community to that food supply. A high-resolution, time-lapse camera deployed separately at the research site collected one image per hour for a period of six months between servicing. These images provide a record of the changes in the supply of large particulate matter which serve as a food supply for benthic organisms. A third tool for these kinds of studies, the Lagrangian sediment trap used to measure food supply in the water column, was refined and tested in Monterey Bay.

Precision Control Technologies for ROVs and AUVs

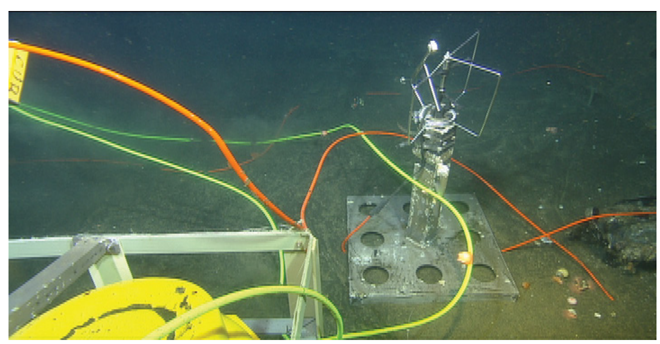
Project leads: Rob McEwen, Michael Risi, Steve Rock
Project manager: Steve Rock
Project team: James Barry, David Caress, Brett Hobson, Charles Paull, Brian Schlining, Hans Thomas

The ability to navigate and control MBARI's ROVs with respect to steep and complex canyon walls was demonstrated. The approach employed calculates in real time the perpendicular direction to the terrain and then controls the ROV to keep the camera (or other instruments) aligned with that direction. The demonstration resulted in improved image quality and data collection. In addition, work on terrain-relative navigation continued with the goal of enabling an AUV to determine its position with respect to pre-stored bathymetric data. This capability would eliminate the need to surface an AUV to obtain a GPS fix to correct the navigation estimate. Instead, equivalent fixes are obtained by correlating altitude measurements with terrain maps. A significant result during 2010 was the first successful demonstration of real-time, closed-loop control of an AUV using terrain-relative navigation and a non-inertial grade navigation system. In multiple trials the AUV returned to a specified location in Soquel Canyon with approximately five-meter accuracy.

Prototype Multi-Sensor Ocean Floor Observatory on the MARS Cable

Project leads: Paul McGill, Barbara Romanowicz
Project manager: Paul McGill
Collaborator: Doug Neuhauser, University of California, Berkeley

The Monterey Ocean Bottom Broadband (MOBB) seismometer is the longest-running ocean-bottom broadband seismometer in the world. Although first installed on the seafloor in 2002 as a stand-alone instrument, in 2009, MOBB was connected to the MARS observatory. Fishing trawlers snagged the cable twice in 2009 and again in early 2010, when the cable became severed and the MOBB equipment was seriously damaged. The damaged equipment was then recovered. The team has decided to bury the replacement cable in the seafloor sediment to protect it from fishing operations. The cable-laying ROV toolsled was modified to bury cable, then the cable was buried six-to-nine inches deep with minimal disturbance to the seafloor sediment. The MOBB system is scheduled to be redeployed in 2011. Work also continued on reduction of background noise from ocean waves and currents so that the MOBB seafloor data can be incorporated into the Northern California earthquake notification system.



Fishing trawlers damaged equipment and severed the cable connecting the MOBB site to the MARS network.

Renewable At Sea Power/PowerBuoy

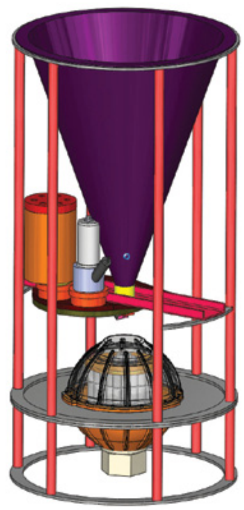
Project lead: Andrew Hamilton
Project team: James G. Bellingham, Francois Cazenave, Jon Erickson, Paul McGill, Wayne Radachonski

The PowerBuoy project is developing a self-contained wave-energy harvesting device for the purpose of providing electrical power to remote oceanographic equipment. Power is a limiting factor in many observing scenarios and this project aims to provide a higher level of power than is available from traditional solar- and wind-powered applications. In 2010 the project team performed considerable design and component testing work leading to a field test.

Sedimentation Event Sensor

Project leads: Paul McGill, Ken Smith
Project manager: Paul McGill
Project team: Rich Henthorn, Brett Hobson, Alana Sherman

The sedimentation event sensor is a sediment trap fitted with cameras to record both visible-light and fluorescence macro-images of collected sediment, thus measuring the quantity and quality of particulate food reaching the seafloor. A rotating sample plate will allow the collected material to be imaged for composition and size, and measured for chlorophyll content. Initial design work was completed, including the writing of functional and design requirements, the purchase of computer hardware, the construction of a titanium frame, and the development of a driving mechanism to rotate the sample plate. The sensor will be tested on the MARS observatory before being deployed at Station M, an abyssal plain 4,000 meters deep off the central California coast.



The design of a sedimentation event sensor for long-term studies of material that falls to the deep seafloor.

SENSORS: Ocean Observing System Instrument Network Infrastructure and Technology Transfer: Observatory Software

Project lead/manager: Duane Edgington
Project team: Kevin Gomes, Kent Headley, Bob Herlien, Tom O'Reilly

Several collaborations were developed to transfer MBARI observatory software technologies—software infrastructure middleware, PUCK protocol, and the Shore-Side Data System—to external observatory projects, industry groups, and standards organizations. Among the projects employing these technologies are the ESONET European cabled observatory, an NSF/NOAA under-the-ice project, and buoys in the Great Lakes. The PUCK Reference Design Kit was distributed to potential "plug and work" protocol adopters and a supply of kits was pre-assembled and tested to reduce the lead time for requests. Several key pieces of documentation were written in 2010 to enable transfer of software infrastructure applications to external users. DataTurbine (software for managing real-time data streams) was integrated into the software infrastructure applications to provide instant data visualization. A prototype tool was developed for web-based visualization of geo-located point data in real-time.

Video Annotation and Analysis Presentation (VAAP)

Project leads: Steven Haddock, Charles Paull, Brian Schlining
Project manager: Nancy Jacobsen Stout
Project team: Lori Chaney, Linda Kuhnz, Lonny Lundsten, Kyra Schlining, Susan von Thun

The VAAP system attempts to develop an analytical method for assessing biological communities and exploring their functional relationships. Quantitative and qualitative data sets were created from existing data collected by MBARI ROVs. A web-based interface component, the Deep-Sea Guide, was created as the portal for accessing these data and related products. Researchers have begun using this interface to explore new ways of evaluating data quality and to update identifications, verify ancillary data, enrich descriptions, and improve access to the data. The team continued populating the database, which serves as an encyclopedia for the deep sea, and refined the tools and data products. The goal is to publish the Deep-Sea Guide as a visual tool for educational and public outreach.

The Deep-Sea Guide provides images, descriptions, and other information on thousands of deep-sea animals.

Video Monitoring to Improve Pacific Lamprey Passage

Project lead/manager: Danelle Cline
Project team: Duane Edgington
Collaborators: Frank Loge and Donald Thompson, University of California, Davis

This collaboration explores the suitability of using the Automated Visual Event Detection software to monitor Pacific lampreys in video recorded at the McNary Dam in Oregon. These fish are born in freshwater, swim out to the ocean as adults, and return to the freshwater to reproduce. Pacific lamprey are an important ceremonial food for Native American tribes in the Columbia River basin. The decline of Pacific lamprey populations in the Columbia and Snake Rivers is a growing concern for tribal, state, and federal agencies. Recovery of the dwindling populations of lampreys is dependent on improving successful passage of migrating adult fish through hydropower projects as they make their way upstream to spawning grounds. The goals of this work are to generate quantitative estimates of adult Pacific lampreys and salmonoids from video taken at the dam and to monitor fish behavior.

Zooplankton Biodiversity and Bio-Optics in the Deep Sea

Project lead/manager: Steven Haddock
Project team: Lynne Christianson, Warren Francis, Gerard Lambert, Amy McDermott, Meghan Powers, Nathan Shaner
Collaborators: William Browne, University of Miami, Florida; Allen Collins, Smithsonian Institution, Washington, D.C.; Rob Condon, Bermuda Institute of Ocean Sciences, St. George's; Casey Dunn and Rebecca Helm, Brown University, Providence, Rhode Island; Monty Graham, University of South Alabama, Mobile; Mikhail Matz, University of Texas, Austin; Claudia Mills, University of Washington; Mark Moline, California State Polytechnic University, San Luis Obispo; Karen Osborn, Scripps Institution of Oceanography, La Jolla, California; Gustav Paulay, University of Florida, Gainesville; Philip R. Pugh, National Oceanography Centre, Southampton, United Kingdom; Bruce Robison, MBARI; Brad Seibel, University of Rhode Island, Kingston; Alison Sweeney, University of California, Santa Barbara; Erik Thuesen, Evergreen State College, Olympia, Washington

It is important to establish a baseline of gelatinous species quickly because imminent changes in their populations are expected as a result of changing ocean conditions. Studies of deep-sea gelatinous animals using morphological and molecular techniques have resulted in the rearrangement of phylogenetic trees and taxonomic classifications. Three new species of siphonophores were described in 2010, including one which may be a biological indicator of water-mass type; it also has fluorescent lures to attract krill prey. Bio-optics research resulted in the revelation of a fluorescent protein in a comb jelly, a new bioluminescent chaetognath (a deep-sea worm), and a novel family of "green bomber" worms which use bioluminescent emissions to evade predators. A comprehensive review cataloged more than 40 independent evolutionary events leading to luminescence. These findings suggest that bio-optical communication serves a central role for ocean animals.

Awards

Peter G. Brewer

United Kingdom Royal Academy of Engineering Distinguished Visiting Fellowship, Heriot-Watt University, Edinburgh, Scotland

Zheng Zhong Distinguished Visiting Fellowship, Xiamen University, Fujian, China

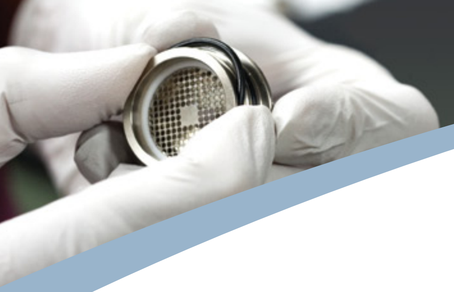
George I. Matsumoto

Ocean Science Leadership Award Commitment to Education, QuikScience Challenge and Centers for Ocean Sciences Education Excellence West

Environmental Sample Processor Team

(James Birch, Cheri Everlove, Scott Jensen, Roman Marin III, Doug Pargett, Christina Preston, Brent Roman, Chris Scholin)

Federal Laboratory Consortium for Technology Transfer, Far West Region, Outstanding Regional Partnership awarded to Lawrence Livermore National Laboratory, MBARI, and Spyglass Biosecurity, Inc.



Invited Lectures

Nancy Barr

Guild of Natural Science Illustrators, Seaside, California

James P. Barry

Monterey Bay Aquarium, Monterey, California

Stanford University, California

Keynote Address, Southern California Coastal Water Research Project, Long Beach, California

American Physiological Society, Denver, Colorado

California Polytechnic State University, San Luis Obispo

National Oceanographic and Atmospheric Administration (NOAA) Benthic Habitat Characterization Workshop, Sidney, British Columbia, Canada

Ocean Sciences Meeting, Portland, Oregon

European Project on Ocean Acidification, Kiel, Germany

U.S. Senate Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard, Washington, D.C.

U.S. Office of Management and Budget, Washington, D.C.

U.S. State Department, Office of Polar and Ocean Affairs, Washington, D.C.

Aspen Institute Environmental Forum, Colorado

Chevron Corporation, San Ramon, California

Blue Ocean Film Festival, Monterey, California

Ocean Acidification Workshop, NOAA Fisheries, Seattle, Washington

American Association for the Advancement of Science, San Francisco, California

James G. Bellingham

Keynote Presentation, Oceanic Engineering Society-IEEE Autonomous Underwater Vehicles Conference, Monterey, California

American Geophysical Union, San Francisco, California

University of Wisconsin, Madison

James Birch

Arizona State University, Tempe

Marine Technology Society TechSurge Workshop, Norfolk, Virginia

Peter G. Brewer

Heriot-Watt University, Edinburgh, Scotland

Global Earth Observation System of Systems Workshop, Seattle, Washington

National Key Lab in Oceanography, Qingdao, China

Chinese Academy of Science, Qingdao, China

Nanqiang Lecture, Xiamen University, Fujian, China

California State University, Monterey Bay

Ocean Sciences Meeting, Portland, Oregon

Plymouth Marine Laboratory, Devon, United Kingdom

David Caress

Oceanic Engineering Society-IEEE Autonomous Underwater Vehicles Conference, Monterey, California

Francisco Chavez

Keynote Address, Iberian Seminar on Marine Chemistry, Vigo, Spain

International Panel of Experts on the Peruvian Anchovy, Lima, Peru

National Aeronautics and Space Administration (NASA) Biodiversity and Ecological Forecasting Team Meeting, Washington, D.C.

U.S. Integrated Ocean Observing System, La Jolla, California

International Symposium on Boundary Current Dynamics, Qingdao, China

Integrated Ocean Observing Systems California Workshop, La Jolla, California

Ecological Society of America, Pittsburg, Pennsylvania

Integrated Framework for Sustained Ocean Observations, Paris, France

Ocean Carbon and Biogeochemistry Summer Workshop, La Jolla, California

Ocean Carbon and Biogeochemistry Time Series Scoping Workshop, Honolulu, Hawaii

International Surface Ocean Lower Atmosphere Meeting on Oxygen Minimum Zones, Lima, Peru

American Geophysical Union, San Francisco, California

David Clague

University of California, Berkeley

Scripps Institution of Oceanography, La Jolla, California

University of California, Santa Cruz

Judith Connor

National Science Foundation International Antarctic Biology Course, McMurdo Station, Antarctica

Fulbright Scholar Program, Monterey, California

Stanford University School of Medicine, Stanford, California

Monterey Bay Aquarium, Monterey, California

California Association of Parks and Recreation, Monterey

Sergey Frolov

Stanford University, California

Scripps Institution of Oceanography, La Jolla, California

Steven Haddock

Center for Ocean Solutions Monterey Area Institutions' Network for Education, Pacific Grove, California

Pacific Grove Natural History Museum, California

Monterey Bay National Marine Sanctuary, Monterey, California

California State Summer School for Mathematics and Science, University of California, Santa Cruz

Smithsonian Institution, Washington, D.C.

Monterey Peninsula College, California

Julio Harvey

International Conference on Aquatic Invasive Species, San Diego, California

Bob Herlien

Coral Reef Environmental Observatory Network, University of California, San Diego

Ken Johnson

NOAA Ocean Acidification Workshop, St. Petersburg, Florida

U.S. Argo Science and Implementation Panel Meeting, Seattle, Washington

Ocean Sciences Meeting, Portland, Oregon

Center for Microbial Oceanography: Research and Education, Honolulu, Hawaii

Ocean Carbon and Biogeochemistry Program Scoping Workshop, Honolulu, Hawaii

Shannon Johnson

NOAA Ocean Exploration Teacher Workshop, Long Beach, California

Moss Landing Marine Laboratories, California

Heather Kerkering

University of California, Santa Barbara

University of California, Santa Cruz

Bay Area Ecosystem Climate Change Consortium and Gulf of the Farallones National Marine Sanctuary, San Francisco, California

Coastal Ocean Regional Roundtable Tri-City Series, San Luis Obispo, Santa Cruz, and Monterey, California

Building Relationships Workshop, National Weather Service, San Francisco, California

Marine Protected Areas Federal Advisory Committee and Task Team, Monterey, California

Humboldt Bay Symposium, Eureka, California

William Kirkwood

Chinese Academy of Science, Qingdao, China

Gene Massion

Ocean Observatories Initiative Science Workshop II, Tempe, Arizona

George I. Matsumoto

Alaska Marine Science Symposium, Anchorage

Monterey Bay Aquarium, Monterey, California

Seldovia Tribal Marine Science Workshop, Alaska

Smithsonian Institution, Washington, D.C.

Bishop Museum, Honolulu, Hawaii

Thom Maughan

Ocean Sciences Meeting, Portland, Oregon

Tom O'Reilly

European Seas Observatory Network of Excellence Best Practices Workshop, Marseille, France

Charles Paull

U.S. Department of Energy, Washington, D.C.

U.S. Senate Energy Committee, Washington, D.C.

U.S. Department of Energy Methane Hydrate Advisory Committee, Atlanta, Georgia

ConocoPhillips, Houston, Texas

Rutherford House Public Lecture and Plenary Address, The Seventh International Workshop on Methane Hydrate Research and Development, Wellington, New Zealand

U.S. Geological Survey, Menlo Park, California

California State University, Monterey Bay

San Joaquin Geologic Society, Bakersfield, California

Keynote Address, Sediment Transport Processes in Submarine Canyons and Deep-Sea Channels Offshore of Southwestern Taiwan Workshop, National Taiwan University, Taipei

Colorado School of Mines, Golden

Kanna Rajan

IEEE Silicon Valley Chapters in Computers and Controls, Moffett Field, California

University of Porto, Portugal

Schloss Dagstuhl-Leibniz Center for Informatics, Saarbrucken, Germany

Office National d'Etudes et Recherches Aérospatiales, Toulouse, France

Naval Postgraduate School, Monterey, California

Conference on Computational Sustainability, Massachusetts Institute of Technology, Cambridge

Space Telescope Science Institute, Baltimore, Maryland

European Space Agency, Noordwijk, Holland

Steve Ramp

Ocean Sciences Meeting, Portland, Oregon

Eastern Pacific Ocean Prediction Forum, West Coast Modeling Workshop, Portland, Oregon

Monterey Peninsula College, California

National Weather Service, Monterey, California

National Product Developers Workshop, Ann Arbor, Michigan

National Science Foundation Conference on Nonlinear Internal Waves, Ann Arbor, Michigan

National Academy of Sciences Ocean Studies Board, Seattle, Washington

California and the World Ocean Conference, San Francisco, California

Erika Raymond

Ocean Sciences Meeting, Portland, Oregon

Bruce Robison

Ocean Sciences Meeting, Portland, Oregon

Hopkins Marine Station of Stanford University, Pacific Grove, California

Blue Ocean Film Festival, Monterey, California

Steve Rock

Lockheed Martin Space Corporation, Palo Alto, California

Technische Universität, Dresden, Germany

Christopher Scholin

Ocean Sciences Meeting, Portland, Oregon

Monterey Bay National Marine Sanctuary, Monterey, California

David and Lucile Packard Foundation, Los Altos, California

Panetta Institute for Public Policy, Seaside, California

U.S. Department of Homeland Security, Washington, D.C.

The 14th Biennial Challenger Conference for Marine Science, University of Southampton, United Kingdom

H. Burr Steinbach Visiting Scholar, Woods Hole Oceanographic Institution, Massachusetts

Alana Sherman

International Conference on Robotics and Automation, Anchorage, Alaska

William Ussler

Group on Earth Observations Biodiversity Observation Network Implementation Planning Meeting, Pacific Grove, California

American Geophysical Union, San Francisco, California

Robert C. Vrijenhoek

Berry College, Rome, Georgia

Duke University Marine Laboratory, Beaufort, North Carolina

Tom Wadsworth

NOAA/Marine Advanced Technology Education Workshop, Monterey, California

Alexandra Z. Worden

International Society for Microbial Ecology Congress, Seattle, Washington

Gordon Research Conference on Marine Microbes, Tilton, New Hampshire

14th International Conference on the Cell and Molecular Biology of *Chlamydomonas*, Norton, Maine

Opening Plenary, XXV Congress of the International Society for Advanced Cytometry, Seattle, Washington

5th Annual User Meeting, Joint Genome Institute, Walnut Creek, California

Moss Landing Marine Laboratories, California

C.B. van Niel Lecture, Hopkins Marine Station of Stanford University, Pacific Grove, California

Ocean Sciences Meeting, Portland, Oregon

Yanwu Zhang

Northwestern Polytechnic University, Xi'an, China

Mentorships

Nancy Barr

Christopher Matthews, undergraduate summer intern, University of California, Santa Cruz (creating web sites about autonomous underwater vehicles and the Controlled, Agile, and Novel Observing Network)

James P. Barry

Eric Pane, postdoctoral fellow (effects of climate change and ocean acidification on the physiology of deep-sea animals)

Matthew Russell, undergraduate summer intern, Flinders University (Acid Ocean: a web based tool to communicate and present ocean acidification research)

Josi Taylor, postdoctoral fellow (effects of anthropogenic changes in ocean conditions on the physiology of marine animals)

James G. Bellingham

Sergey Frolov, postdoctoral fellow (design of optimal observatories for algal bloom monitoring and prediction)

James G. Bellingham, Sergey Frolov

Sergi Pon Freixes, Ph.D. student (validation of the fast repetition rate fluorometer measurements of primary productivity in Monterey Bay)

James G. Bellingham, Sergey Frolov, Yanwu Zhang

Bartolome Garau, graduate summer intern, University of the Balearic Islands (optimal survey planning for mobile observing platforms)

Katherine Morrice, graduate summer intern, Moss Landing Marine Laboratories (nutrient supply due to intermediate mixing events and implications for sampling strategies)

James Birch, Julie Robidart

Sara Thomas, undergraduate summer intern, University of Hawaii at Manoa (design and optimization of molecular assays for the Environmental Sample Processor)

James Birch, Alexandra Z. Worden

Elif Demir-Hilton, postdoctoral fellow (quantitative approaches for enumerating picophytoplankton taxa and in situ detection and enumeration of microorganisms using the ESP)

Larry Bird

Aaron Schnittger, undergraduate summer intern, Cabrillo College (shackle for remotely operated vehicle manipulator operations)

Peter G. Brewer

Andreas F. Hofmann, postdoctoral fellow (chemical and physical limits to aerobic marine life)

Peter G. Brewer, Edward Peltzer

Melissa Luna, undergraduate summer intern, College of Charleston (determining the pH of marine pore water from the in situ Raman spectra of dissolved sulfide)

Francisco Chavez

Monique Messié, postdoctoral fellow (study of the Peru upwelling ecosystem, with comparisons to California and other upwelling systems)

Sasha Tozzi, postdoctoral fellow (microbial energy cycle in the ocean)

David Clague

Nichelle Baxter, Ph.D. student, University of Florida, Gainesville (origin of near-ridge seamount chains)

Marilena Calarco, Ph.D. student, University of Rome (submarine geology of Pantelleria)

Levin Castillo, M.S. student, University of Quebec at Chicoutimi (large Archean lava flows and modern analogs)

Danilo Cavallero, Ph.D. student, University of Catania, Italy (the submarine geology of Etna Volcano)

Iain Faichney, Ph.D. student, Townsville University (formation of drowned coral reefs, Maui-Nui Complex, Hawaii)

Christoph Helo, Ph.D. student, McGill University (formation of clastic deposits at Axial Seamount)

Charlotte Humphrey, Ph.D. student, Manchester Metropolitan University (bioerosion of fossil reefal carbonates)

Bruce Pauley, Ph.D. student, University of California, Davis (formation of palagonite)

Jonathan Weiss, Ph.D. student, University of Hawaii, Honolulu (drowned reefs along the Hawaiian volcanic chain)

Isobel Yeo, graduate summer intern, Durham University (new insights into diking processes from high-resolution bathymetry)

Danelle Cline, Duane Edgington, George Matsumoto

Katie Lodes, educator summer intern, St. Joseph's Academy for Girls (student eyes in the sea: a look at benthic megafaunal biodiversity and behavior from a deep-sea observatory)

Judith Connor

Katie Mach, Ph.D. student, Stanford University (wave-induced hydrodynamic forces on intertidal seaweeds)

Kevin Miklasz, Ph.D. student, Stanford University (reproductive strategies in articulated coralline algae)

Steven Haddock

Liza Gomez Daglio, Ph.D. student, University of California, Merced (jellyfish diversity and biogeography)

Warren Francis, M.S. student, University of California, Santa Cruz (chemistry of marine luminescence)

Jennifer Harris, M.S. student, University of California, San Francisco (nudibranch phylogenetics and bioluminescence)

Amy McDermott, undergraduate student, University of California, Santa Cruz (characterization of novel luminescent systems)

Meghan Powers, M.S. student, University of California, Santa Cruz (novel luciferases)

Nathan Shaner, Helen Hay Whitney postdoctoral fellow (biosynthesis of coelenterazine)

Holly Swift, Ph.D. student, University of California, Merced (plankton evolution and genetics)

Andrew Hamilton

Roman Marin IV, undergraduate summer intern, Cabrillo College (wave energy for vertical profiling)

Kent Headley, Tom O'Reilly

Daniel Mihai Toma, Ph.D. summer intern, Technical University of Catalonia (interoperable marine monitoring system)

Rich Henthorn

John Virrey III, undergraduate summer intern, Bakersfield College (preparing the sedimentation event sensor for integration of control software from the Benthic Rover)

Shannon Johnson

Gillian Rhett, M.S. student, Moss Landing Marine Laboratories (meiofauna associated with whale falls)

Chad Kecy

Spencer Matteson, undergraduate summer intern, University of California, Santa Cruz (design and layout of an environmental sensor board for oceanographic instrumentation)

Linda Kuhnz

Joshua Barraza, high school student, Pajaro Valley High School (native dune habitats)

Adriana Briceno, undergraduate student, San Jose State University (native dune habitats)

Dyani Jacobo, high school student, Pajaro Valley High School (native dune habitats)

Jose Ramirez, high school student, Pajaro Valley High School (native dune habitats)

Eddy Reyes, high school student, Pajaro Valley High School (native dune habitats)

Eddie Sumano, undergraduate student, University of California, San Francisco (native dune habitats)

Linda Kuhnz, Alana Sherman, Ken Smith,

Rebecca Hunter, graduate summer intern, University of Glasgow (biological community monitoring using the Benthic Rover)

George I. Matsumoto

Diego Gonzales, high school student, Pajaro Valley High School (*Pseudo-nitzschia*: tiny creatures can have a big impact)

Dulce Guzman, high school student, Pajaro Valley High School (comparing urbanized and non-urbanized beaches)

Julie Huang, high school student, Pajaro Valley High School (aquatic invertebrates: indicators of water quality in Watsonville Slough)

Xianjia Huang, high school student, Pajaro Valley High School (comparing urbanized and non-urbanized beaches)

Jose Jimenez, high school student, Pajaro Valley High School (*Pseudo-nitzschia*: tiny creatures can have a big impact)

Josh Jimenez, high school student, Pajaro Valley High School (aquatic invertebrates: indicators of water quality in Watsonville Slough)

Jorge Juarez, high school student, Pajaro Valley High School (aquatic invertebrates: indicators of water quality in Watsonville Slough)

Breanna Mireles, high school student, Pajaro Valley High School (comparing urbanized and non-urbanized beaches)

Elisabet Moya, high school student, Pajaro Valley High School (*Pseudo-nitzschia*: tiny creatures can have a big impact)

Edith Parades, high school student, Pajaro Valley High School (comparing urbanized and non-urbanized beaches)

Alicia Reyes, high school student, Pajaro Valley High School (*Pseudo-nitzschia*: tiny creatures can have a big impact)

Katherine Sholl, high school student, Monterey Academy of Oceanographic Sciences, Monterey High School (ocean conservation through comics)

Thom Maughan, Kanna Rajan

Jnaneshwar Das, Ph.D. student, University of Southern California (decision support system)

Sandeep Kumar, undergraduate summer intern, Indian Institute of Technology (visualization of plans for autonomous underwater vehicles and hidden Markov models estimation reactor)

Charles Paull

Jon Furlong, Ph.D. student, University of Victoria (neotectonics of Cascadia Margin)

Katie Maier, Ph.D. student, Stanford University (AUV surveys of Lucia Chica deep-water channels)

Tim Pennington

Marc Miller, undergraduate intern, Monterey Peninsula College (processing samples for ^{15}N-nitrate and -ammonia uptake by Monterey Bay phytoplankton)

Kanna Rajan

Sergio Jiminez Celorro, Ph.D. student, University of Carlos III de Madrid (hidden Markov models for dynamic ocean features)

Lukas Chrpa, postdoctoral scholar, Fulbright fellowship, Charles University, Prague (multi-vehicle planning and control)

Rishi Graham, postdoctoral fellow (distributed autonomy)

Angel Garcia Olaya, assistant professor, University of Carlos III de Madrid (utility-based multi-criteria approaches to sampling dynamic ocean fields)

Zhengyu Yin, Ph.D. student, University of Southern California (continuous time planning with decentralized Markov decision processes)

Erika Raymond

Gregor Bwye, undergraduate student, University of Aberdeen (observed patterns in deep-sea video)

Bruce Robison

Hendrik Jan Ties Hoving, postdoctoral fellow (investigating the means to determine the age of deep-living squids and other invertebrates)

Sam Urmy, Ph.D. student, University of Washington (upward-looking sonar characterization of nekton and micronekton over Monterey Canyon)

Steve Rock

Sean Augenstein, Ph.D. student, Stanford University (feature-based navigation)

Sarah Houts, Ph.D. student, Stanford University (terrain-based navigation for AUVs)

Peter Kimball, Ph.D. student, Stanford University (terrain-based navigation for AUVs)

Debbie Meduna, Ph.D. student, Stanford University (terrain-based navigation for AUVs)

Kiran Murthy, Ph.D. student, Stanford University (benthic mosaicking and navigation)

Jose Padial, Ph.D. student, Stanford University (feature-based navigation)

Stephen Russell, Ph.D. student, Stanford University (servicing of tethered instruments and moorings)

Brian Schlining

Hana Hashim, undergraduate summer intern, San Jose State University (the Deep-Sea Guide: a front-end designer's look)

Christopher Scholin

Kevan Yamahara, early career fellow, Center for Ocean Solutions (adapting MBARI's Environmental Sample Processor for use in water quality tests)

Rob Sherlock

Alexander Schramm, high school student, Pacific Grove High School (cataloging preserved specimens and extracted DNA)

Ken Smith

Michael Vardaro, postdoctoral fellow (deep-sea bioturbation and the role of the echinoid, *Echinocrepis rostrata*)

Stephanie Wilson, postdoctoral fellow (particle flux associated with zooplankton feeding/defecation in the deep midwater)

Sebastian Sudek, Alexandra Z. Worden

Hang Yu, undergraduate summer intern, University of British Columbia (identification of new phytoplankton isolates)

Robert C. Vrijenhoek

Erika Raymond, postdoctoral fellow, Schmidt Ocean Institute (development of autonomous fish tissue sampler)

Norah Saarman, Ph.D. student, University of California, Santa Cruz (mussel phylogeography and larval biology)

Andrew Thaler, Ph.D. student, Duke University (phylogeography of *Ifremeria* snails)

Alexandra Z. Worden

Harriet Alexander, undergraduate student, Wellesley College (molecular phylogenetic characterization of Monterey Bay to open-ocean phytoplankton communities)

Marie L. Cuvelier, Ph.D. candidate, Rosenstiel School of Marine and Atmospheric Science, University of Miami (growth and grazing mortality rates of uncultivated globally important picophytoplankton taxa)

Yun-Chi Lin, visiting scholar, Taiwan (molecular phylogenetics of natural eukaryotic microbial communities)

Darcy McRose, M.S. student, Stanford University (the role of vitamins in regulating growth of environmentally relevant *Micromonas* clades)

Adam Monier, postdoctoral fellow (metagenomics of microbial communities across a gradient of marine biomes)

Melinda P. Simmons, Ph.D. student, University of California, Santa Cruz (conserved introner elements and representation in natural phytoplankton populations)

Valeria Jimenez, Ph.D. student, University of California, Santa Cruz (pico-prasinophyte ecology and evolution)

Peer-Reviewed Publications

Alford, M.H., R.C. Lien, H. Simmons, J. Klymak, **S.R. Ramp**, Y.J. Yang, T.Y. Tang, D. Farmer, and M.H. Chang (2010). Speed and evolution of nonlinear internal waves transitioning the south China Sea. *Journal of Physical Oceanography*, **40**: 1338-1355.

Audzijonyte, A. and **R.C. Vrijenhoek** (2010). Three nuclear genes for phylogenetic, SNP and population genetic studies of molluscs and other invertebrates. *Molecular Ecology Resources*, **10**: 200-204.

Audzijonyte, A. and **R.C. Vrijenhoek** (2010). When gaps really are gaps: Statistical phylogeography of hydrothermal vent invertebrates. *Evolution*, **64**: 2369-2384.

Barry, J.P., J.M. Hall-Spencer, and T. Tyrrell (2010). In situ perturbation experiments: Natural venting sites, spatial/temporal gradients in ocean pH, manipulative in situ pCO_2 perturbations. In: *Best Practices for Ocean Acidification Research*, edited by U. Riebesell, V.J. Fabry, L. Hansson, and J.P. Gattuso. European Commission, pp. 123-136.

Barry, J.P., T. Tyrrell, L. Hansson, G.K. Plattner, and J.P. Gattuso (2010). Atmospheric CO_2 targets for ocean acidification perturbation experiments. In: *Best Practices for Ocean Acidification Research*, edited by U. Riebesell, V.J. Fabry, L. Hansson, and J.P. Gattuso. European Commission, pp. 53-63.

Bayha, K.M., M.N. Dawson, A.G. Collins, M.S. Barbeitos, and **S.H.D. Haddock** (2010). Evolutionary relationships among scyphozoan jellyfish families based on complete taxon sampling and phylogenetic analyses of 18S and 28S ribosomal DNA. *Integrative and Comparative Biology*, **50**: 436-455.

Bellingham, J.G. (2010). Platforms: Autonomous underwater vehicles. In: *Measurement Techniques, Platforms and Sensors*, edited by J.H. Steele, S.A. Thorpe, and K.K. Turekian. Elsevier, pp. 162-173.

Bjorkstedt, E.P., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, B. Peterson, B. Emmett, J. Peterson, R. Durazo, G. Gaxiola-Castro, **F.P. Chavez**, **J.T. Pennington**, C.A. Collins, J. Field, S. Ralston, K. Sakuma, S.J. Bograd, F.B. Schwing, Y. Xue, W.J. Sydeman, S.A. Thompson, J.A. Santora, J. Largier, C. Halle, S. Morgan, S.Y. Kim, K.P.B. Merkens, J.A. Hildebrand, and L.M. Munger (2010). State of the California Current 2009-2010: Regional variation persists through transition from La Niña to El Niño (and back?) *California Cooperative Oceanic Fisheries Investigations Report*, **51**: 39-69.

Boudreau, B.P., J.J. Middelburg, **A.F. Hofmann**, and F.J.R. Meysman (2010). Ongoing transients in carbonate compensation. *Global Biogeochemical Cycles*, **24**: doi:10.1029/2009GB003654.

Burd, A.B., D.A. Hansell, D.K. Steinberg, T.R. Anderson, J. Aristegui, F. Baltar, S.R. Beaupre, K.O. Buesseler, F. DeHairs, G.A. Jackson, D.C. Kadko, R. Koppelmann, R. Lampitt, T. Nagata, T. Reinthaler, C. Robinson, **B. Robison**, C. Tamburini, and T. Tanaka (2010). Assessing the apparent imbalance between geochemical and biochemical indicators of meso- and bathypelagic biological activity: What the @$#! is wrong with present calculations of carbon budgets? *Deep-Sea Research Part II*, **57**: 1557-1571.

Castillo, P., **D. Clague**, A. Davis, and P.F. Lonsdale (2010). Petrogenesis of Davidson Seamount lavas and its implications for fossil spreading center and intraplate magmatism in the eastern Pacific. *Geochemistry, Geophysics, Geosystems*, **11**: doi:10.1029/2009GC002992.

Chadwick, W.W., D. Butterfield, R.W. Embley, V. Tunnicliffe, J.A. Huber, S.L. Nooner, and **D. Clague** (2010). Spotlight 1: Axial Seamount. *Oceanography*, **23**: 38-39.

Chen, Y., **W. Ussler III**, H. Haflidason, B.O. Hjelstuen, A. Lepland, V. Melezhik, L. Rise, E. Vaular, and I.H. Thorseth (2010). Sources of methane inferred from pore-water $\delta^{13}C$ of dissolved inorganic carbon in Pockmark G11, offshore Mid-Norway. *Chemical Geology*, **275**: 127-138.

Clague, D., J.C. Braga, D. Bassi, P.D. Fullagar, W. Renema, and J.M. Webster (2010). The maximum age of Hawaiian terrestrial lineages: Geological constraints from Koko Seamount. *Journal of Biogeography*, **37**: 1022-1033.

Clague, D., L. Lundsten, J. Hein, **J. Paduan**, and A. Davis (2010). Spotlight 6: Davidson Seamount. *Oceanography*, **23**: 126-127.

Cuvelier, M.L., A.E. Allen, **A. Monier**, J.P. McCrow, **M. Messié**, S.G. Tringe, T. Woyke, R.M. Welsh, T. Ishoey, J.H. Lee, B.J. Binder, C.L. DuPont, M. Latasa, C. Guigand, **K.R. Buck,** J. Hilton, M. Thiagarajan, E. Caler, B. Read, R.S. Lasken, **F.P. Chavez**, and **A.Z. Worden** (2010). Targeted metagenomics and ecology of globally important uncultured eukaryotic phytoplankton. *Proceedings of the National Academy of Sciences*, **107**: 14679-14684.

Das, J., **F. Py**, **T. Maughan**, **J. Ryan**, **K. Rajan**, and G. Sukhatme (2010). Simultaneous tracking and sampling of dynamic oceanographic features with autonomous underwater vehicles and Lagrangian drifters. *Proceedings of the International Symposium on Experimental Robotics*, New Delhi, India.

Das, J., **K. Rajan**, **S. Frolov**, **J. Ryan**, **F. Py**, D. Caron, and G. Sukhatme (2010). Towards marine bloom trajectory prediction for AUV mission planning. *Proceedings of the*

International Conference on Robotics and Automation, Anchorage, Alaska.

Davis, A., **D. Clague**, **J. Paduan**, B. Cousens, and J.J. Huard (2010). Origin of volcanic seamounts at the continental margin of California related to changes in plate margins. *Geochemistry, Geophysics, Geosystems*, **11**: doi:10.1029/2010GC003064.

Faichney, I.D.E., J.M. Webster, **D. Clague**, **J. Paduan**, and P.D. Fullagar (2010). Unraveling the tilting history of the submerged reefs surrounding Oahu and the Maui-Nui Complex, Hawaii. *Geochemistry, Geophysics, Geosystems*, **11**: doi:10.1029/2010GC003044.

Faichney, I.D.E., J.M. Webster, **D. Clague,** D. Potts, J.C. Braga, and W. Renema (2010). The impact of the mid-Pleistocene transition on the composition of submerged reefs of the Maui-Nui Complex, Hawaii. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **299**: 493-5036.

Fleeger, J.W., D.S. Johnson, K.R. Carman, P.B. Weisenhorn, A. Gabriele, D. Thistle, and **J.P. Barry** (2010). The response of nematodes to deep-sea CO_2 sequestration: A quantile regression approach. *Deep-Sea Research Part I*, **57**: 696-707.

Graham, R. and J. Cortes (2010). Generalized multicircumcenter trajectories for optimal design under near independence. *Proceedings of the Institute of Electrical and Electronics Engineers Conference on Decision and Control*, Atlanta, Georgia.

Greenberg, J.A., **C. Rueda**, E.L. Hestir, M.J. Santos, and S.L. Ustin (2010). Least cost distance analysis for spatial interpolation. *Computers and Geosciences*, **37**: doi:10.1016/j.cageo.2010.05.012.

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Hearty, P.J., J.M. Webster, **D. Clague**, D.S. Kaufman, J. Bright, J. Southon, and W. Renema (2010). A pulse of ooid formation in Maui Nui (Hawaiian Islands) during Termination I. *Marine Geology*, **268**: 152-162.

Hilário, A., **S.B. Johnson**, M.R. Cunha, and **R.C. Vrijenhoek** (2010). High diversity of frenulates (Polychaeta: Siboglinidae) in the Gulf of Cadiz mud volcanoes: A DNA taxonomy analysis. *Deep-Sea Research Part I*, **57**: 143-150.

Hofmann, A.F., J.J. Middelburg, K. Soetaert, D.A. Wolf-Gladrow, and F.J.R. Meysman (2010). Proton cycling, buffering, and reaction stoichiometry in natural waters. *Marine Chemistry*, **121**: 246-255.

Hofmann, A.F., K. Soetaert, J.J. Middelburg, and F.J.R. Meysman (2010). AquaEnv: An aquatic acid-base modelling environment in R. *Aquatic Geochemistry,* **16**: 507-546.

Hofmann, G.E., **J.P. Barry**, P.J. Edmunds, R.D. Gates, D.A. Hutchins, T. Klinger, and M.A. Sewell (2010). The effects of ocean acidification on calcifying organisms in marine ecosystems: An organism to ecosystem perspective. *Annual Review of Ecology, Evolution and Systematics,* **41**: 127-147.

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Ilyina, T., R.E. Zeebe, and **P. Brewer** (2010). Predicting an ocean increasingly transparent to sound at marine mammal frequencies. *Nature Geoscience*, **3**: 18-22.

Jiminez, S., **F. Py**, and **K. Rajan** (2010). Learning identification models for in-situ sampling of ocean features. *Proceedings of the Robotics Systems Sciences Workshop on Active Learning for Robotics*, Zargosa, Spain.

Johnson, K.S. (2010). Simultaneous measurements of nitrate, oxygen, and carbon dioxide on oceanographic moorings: Observing the Redfield ratio in real-time. *Limnology and Oceanography*, **55**: 615-627.

Johnson, K.S., S.C. Riser, and D.M. Karl (2010). Nitrate supply from deep to near-surface waters of the north Pacific subtropical gyre. *Nature*, **465**: 1062-1065.

Johnson, S.B., A. Warén, R. Lee, Y. Kanno, A. Kaim, A. Davis, E. Strong, and **R.C. Vrijenhoek** (2010). *Rubyspira*, new genus and two new species of bone-eating deep-sea snails with ancient habits. *Biological Bulletin*, **219**: 166-177.

Kahn, A.S., **G.I. Matsumoto**, Y.M. Hirano, and A.G. Collins (2010). *Haliclystus californiensis*, a "new" species of stauromedusa (Cnidaria: Staurozoa) from the northeastern Pacific. *Zootaxa*, **2518**: 49-59.

Klapp, S.A., M.M. Murshed, T. Pape, H. Klein, G. Bohrmann, **P. Brewer**, and W.F. Kuhs (2010). Mixed gas hydrate structures at the Chapopote Asphalt Volcano, southern Gulf of Mexico. *Earth and Planetary Science Letters*, **299**: 207-217.

Knepp, T.N., J. Bottenheim, M. Carlsen, D. Carson, D. Donohoue, **G.E. Friederich**, P.A. Matrai, S. Netcheva, D.K. Perovich, R. Santini, P.B. Shepson, W. Simpson, T. Valentic, C. Williams, and P.J. Wyss (2010). Development of an autonomous sea ice tethered buoy for the study of ocean-atmosphere-sea ice-snow pack interactions: The O-buoy. *Atmospheric Measurement Techniques*, **3**: 249-261.

Kouridaki, I., N.P. Polymenakou, A. Tselepides, M. Mandalakis, and **K.L. Smith Jr.** (2010). Phylogenetic diversity of sediment bacteria from the deep northeastern Pacific ocean: Comparison with the deep eastern Mediterranean Sea. *International Journal of Microbiology*, **13**: doi:10.2436/20.1501.

Lester, S.E., K.L. McLeod, H. Tallis, M. Ruckelshaus, B.S. Halpern, P.S. Levin, **F.P. Chavez,** C. Pomeroy, B.J. McCay, C. Costello, S.D. Gaines, A.J. Mace, J.A. Barth, D.L. Fluharty, and J.K. Parrish (2010). Science in support of ecosystem-based management for the U.S. West Coast and beyond. *Biological Conservation*, **143**: 576-587.

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Lundsten, L., **K.L. Schlining**, K. Frasier, **S.B. Johnson**, **L. Kuhnz**, **J. Harvey**, G. Clague, and **R.C. Vrijenhoek** (2010). Time-series analysis of six whale-fall communities in Monterey Canyon, California, USA. *Deep-Sea Research Part I*, **57**: 1573-1584.

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McClain, C.R. and **J.P. Barry** (2010). The role of abrupt topography on species diversity in the deep-sea benthos. *Ecology*, **91**: 964-976.

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On the cover: The mapping autonomous underwater vehicle *D. Allan B.* ready to begin a seafloor mapping survey following launch from the research vessel *Zephyr*. *Photo by Phil Sammet*.

Back cover: Maps of sunken oil tanker SS *Montebello* and one of the Taney Seamounts, created with data collected by the *D. Allan B.* See stories pages 22 and 23.

Inside front cover: Most squids squirt ink outside of their bodies, but this transparent cockatoo squid fills its internal cavity with ink as a form of camouflage. This squid is one of many deep-sea animals highlighted in video clips posted on the MBARI YouTube channel, www.YouTube.com/MBARIvideo.

Inside back cover: An Environmental Sample Processor mounted in a float drifts with the current, sampling for algal blooms as part of the September CANON experiment. The R/V *Western Flyer* followed the drifter for days, while scientists aboard ship evaluated data transmitted by the instrument. *Photo by Phil Sammet*. See story page 11.

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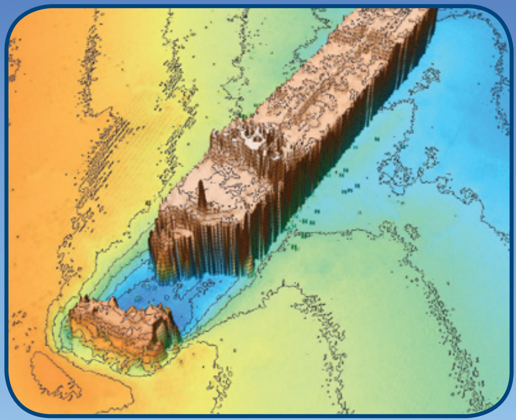

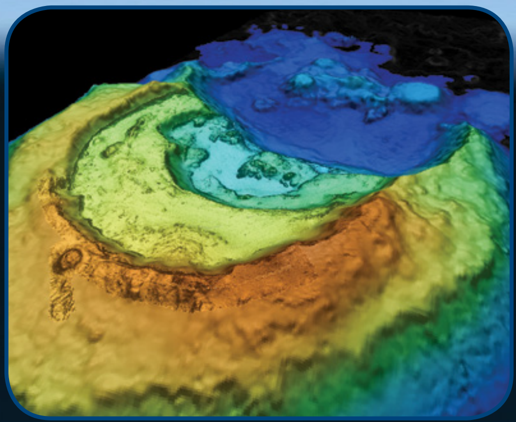

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