# Monterey Bay Aquarium Research Institute

# 2017 Annual Report

A SUMMARY

MAKING AN IMPACT

# MBARI worked around the world in 2017

This year, for the first time, the full Monterey Bay Aquarium Research Institute annual report is published online. This print companion piece provides highlights of the digital version. The map above represents the geographical breadth of the work undertaken by MBARI in 2017. Please visit the online report where you can interact with this map, read the full stories, and watch videos about our work.

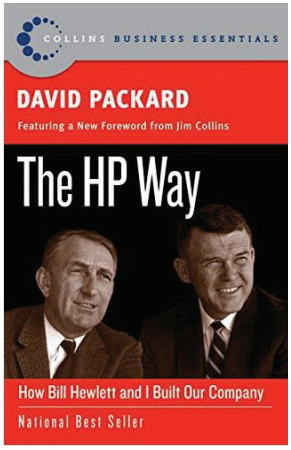
annualreport.mbari.org/2017

Cover photo by Erik Trauschke

Back cover photo by Todd Walsh

# View From the Masthead

In his acclaimed memoir *The HP Way*, David Packard noted, *"As we get older we have the opportunity to look back over many years and see how certain events, seemingly unimportant at the time, had a profound effect in shaping our business or professional careers."* Looking back in the wake of MBARI's 30-year history as a hub for advanced research in ocean science and technology, I think it is fair to say that those words ring true for the institution as a whole as well as for the scientists, engineers, and members of the David and Lucile Packard Foundation who have worked to help bring Packard's unique vision of MBARI to the fore.




The values extolled by MBARI Founder David Packard in his 1995 acclaimed memoir *The HP Way* still ring true to MBARI.

Packard founded MBARI in the spring of 1987 with a vision of fostering a partnership among scientists and engineers. They were to dedicate their energy to designing, building, and using novel instruments and systems to tackle pressing ocean science problems. The ethos of the HP Way was a key founding principle. An emphasis on teamwork, excellence, innovation, respect, and philanthropy were to be among MBARI's guiding values.

Two years later, in his 1989 address to participants of the inaugural meeting of The Oceanography Society, Packard highlighted three technological innovations that he felt would transform oceanography: remotely operated vehicles (ROVs), new sensors, and advanced computer science/data systems. By integrating and building on those core capabilities, he surmised that ocean scientists and engineers would be poised to make incredible discoveries.

A great deal has changed at MBARI since 1989. Back then, MBARI's founding employees made the most of makeshift lab spaces simply designated as either "wet" or "dry". In those early days, efforts to refine the operation of MBARI's first ship, R/V *Point Lobos*, and first ROV, *Ventana*, were all-consuming. Fast forward to 2017: the upgraded version of *Ventana* recently accomplished its four thousandth dive, a testament to its success as a platform for exploration and discovery. And MBARI now occupies a state-of-the-art campus in Moss Landing, California, a far cry from MBARI's original home in Pacific Grove.

An innovative database project was also initiated in the early years of MBARI's founding so that deep-sea ROV observations of marine animals and other features recorded on videotape could be quantified and co-registered with a host of environmental measurements. Today that effort has resulted in over six million observations and over 26,000 hours of recorded video. That unique record has been central to revealing astounding environmental and ecological changes that are taking place locally and that are reflective of similar larger-scale changes afoot elsewhere throughout the global ocean, such as declines in oxygen and increasing acidity. It has also provided the foundation for making many new discoveries, including enigmatic animals such as "bone-eating" worms and parasol sponges, documentation of a complex food web replete with bizarre animals and behaviors, and an extensive

and complex array of gelatinous animals—a "jelly web"—that is now recognized as a significant component of midwater ecosystems worldwide, just to name a few.

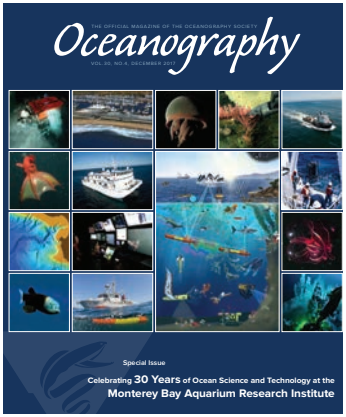
When MBARI began, a concerted effort to establish and standardize sustained chemical and biological observations in Monterey Bay was started. From that initiative sprang new sensors, platforms, and techniques for assessing conditions of the water column in ways that were not necessarily anticipated. Many of the resultant technologies have since been applied on both local and global scales—an embodiment of the "develop local, export global" mantra that now drives much of MBARI's research and development portfolio.

When I joined MBARI in 1992, the R/V *Western Flyer*, MBARI's present-day flagship research vessel, was an artist's rendering on the wall, and ROV *Tiburon*, a custom-made vehicle around which the *Western Flyer* would be built, was still on the drawing board. The new ship and ROV became catalysts for MBARI's ability to conduct studies from Mexico to Hawaii to Canada. Having ready access to the sea beyond the confines of Monterey Bay played an important role in shaping the MBARI of today. *Tiburon* has since been replaced by the ROV *Doc Ricketts*, which completed its thousandth dive in 2017. The *Western Flyer* is approaching the end of its nominal service life, and the design of a new replacement ship is under way. A seagoing capability remains a cornerstone of our vision for the future.

The notion of MBARI developing and operating sophisticated autonomous underwater vehicles (AUVs) came not long after the institute's founding, but at the time such capabilities seemed a distant dream, far from realization—there was much work to be done to build the kind of institute Packard envisioned and to prove its value to the oceanographic community at large. Never could we have imagined the impact that AUVs would have on the global ocean science and technology community, let alone here at MBARI. The types of measurements now being made using fleets of AUVs, from high-resolution seafloor maps to targeted sample collections and persistent global-scale

David Packard was proud to christen the prototype of the new remotely operated vehicle *Tiburon* in 1994.

In 2017, *Oceanography* produced a special edition to celebrate MBARI's 30th anniversary. The volume includes articles by several long-time MBARI researchers. http://tos.org/oceanography/issue/volume-30-issue-04




biogeochemical observations, are truly astounding. As Packard once foresaw, by integrating and building on such core capabilities ocean scientists and engineers are poised now more than ever to make incredible advances.

So if you look closely at the stories highlighted in this year's annual report through the lens of MBARI's 30-year history, you will notice traces of the institute's past and see *"how certain events, seemingly unimportant at the time, had a profound effect"* on shaping the MBARI of today. Packard's directives to concentrate on technology development and foster a culture of science/engineering peer relationships set in motion a sustained surge of innovations and discoveries that prove the value of his long-term vision. Those core values continue to drive MBARI to this day as founding members of the institute retire and new staff take their place, and new initiatives take root in Monterey Bay and far afield. This annual report itself is a signpost of MBARI's evolution as we bring you the full report of the past year's highlights in a new digital format that allows for a much more vibrant and interactive content than has been possible previously.

MBARI routinely refreshes its long-term vision, always anticipating the opportunities and challenges of the coming decades. Our current Strategic Plan and Technology Roadmap capture this forward-looking approach. These planning documents are rooted in the recognition that the oceans are undergoing dramatic ecosystem changes due to a combination of natural forces and human activities, changes readily apparent in the 30-year span since MBARI's founding. They also identify scientific and technological directions that will foster exploration and discovery in the future. Given our current level of ocean ecosystem observation and understanding, it is clear that there are many mysteries to solve and discoveries yet to be made. Now more than ever, in concert with the global ocean science and technology community, we need to embrace MBARI's founding ethos of collaboration, excellence, innovation, respect, and philanthropy. The age of ocean exploration and discovery is far from over.

With that in mind all of us at MBARI look forward to 2018. Follow us by visiting our website, as well as by subscribing to our Facebook, Twitter, YouTube, and Instagram feeds. We hope to hear from you!


Chris Scholin
*President and Chief Executive Officer*

**Related web content**

Values Statement, Strategic Plan, and Technology Roadmap:
www.mbari.org/about/vision

MBARI midwater research has shed light on the physiology, reproduction, and feeding habits of the vampire squid, an ancient animal that shares characteristics with both squid and octopods.

# Thirty years of insights to life in the midwater

Since its inception, MBARI has made a serious commitment to the exploration and study of the ocean midwaters, the vast habitat between the ocean's sunlit upper layers and the dark floor of the deep sea. Prior to the creation of MBARI, no ROV-based midwater research program had ever been attempted. Midwater research and ROV technology are interactive systems that have evolved in tandem and as a result of each other's changes. Midwater expeditions represent about one quarter of dives made by MBARI's remotely operated vehicles, each of which reached milestones in 2017—4,000 dives for ROV *Ventana* and 1,000 dives for the newer ROV *Doc Ricketts*.

The midwater research program has made scientific advances in time series, live animal studies, and the understanding of physical changes in the midwater, as well as the behavior, physiology, feeding, and reproduction of animals that live in the deep. As ROV technology has matured, the scope, scale, and complexity of the research has also advanced, particularly in such areas as observing animal behavior and in situ experimentation, which were virtually impossible before scientists gained direct access to this environment. MBARI's ongoing investment in ROVs and access to the ocean has resulted in unprecedented advances in the understanding of the animals and communities of Earth's largest ecosystem.

**Read the full article**

annualreport.mbari.org/2017/midwater

A heavy tripod frame that was almost completely buried after a sediment-transport event in Monterey Canyon is recovered and brought on board the R/V *Rachel Carson*. Photo by Roberto Gwiazda.

COORDINATED CANYON EXPERIMENT

# Finding the sweet spot of deep-sea sediment flows

Just like mudslides on land, sediment flows on the seafloor can wreak havoc. Telecommunications cables and oil pipelines crisscross the deep sea and any large movement can result in millions of dollars' worth of damage. Given the significant economic impacts, geologists have been working to better understand how, why, and how often sediment moves in seafloor canyons. Over the last two years, MBARI collaborated with researchers from the United Kingdom, China, and the US on the Coordinated Canyon Experiment, which harnessed a wide range of advanced technology to break new ground in the study of canyon dynamics.

**Read the full article**

annualreport.mbari.org/2017/canyon

During the experiment, instruments captured 16 sediment-transport events in Monterey Canyon, documenting their thickness, their velocity structures, the amount of material transported, and how things move on the seafloor. The Coordinated Canyon Experiment illustrates the magnitude of endeavors possible when a long-term institutional commitment to a research area and technology developments over the course of almost two decades are coupled with the collaboration of institutions and colleagues from around the world. No single research group could have pulled it off, but together they have greatly impacted the understanding of deep-sea canyons as well as refined the methods to study them.

Tourists soak in warm waters of the Gardner River while Montana State University graduate student George Platt (center) collects water for the study of brain-eating amoebae. Photo by Kevan Yamahara.

BRAIN-EATING AMOEBAE

# Deep-sea research tools may detect pathogens in Yellowstone National Park

As MBARI technologies evolve over the years, they often make impacts in ways never envisioned at their outset. In 2017, one of MBARI's key instruments for detecting microscopic organisms in the ocean was put to a new use aimed at protecting human health. The Environmental Sample Processor (ESP) was sent to Yellowstone National Park to see if it could monitor tiny but potentially harmful amoebae that live naturally in warm waters and can sometimes cause serious brain damage in humans. This pilot project, funded by the US Geological Survey, showed the ESP can indeed be used to improve monitoring of waters across the United States, another example of fundamental research leading to real-world impacts.

**Read the full article:** annualreport.mbari.org/2017/yellowstone

MBARI's fleet of six long-range autonomous underwater vehicles prior to being launched into Monterey Bay as part of a 2017 experiment. Photo by Susan von Thun.

MONTEREY BAY FIELD EXPERIMENT

# Fleet of robotic vehicles offers glimpse into oceanography of the future

In spring of 2017, scientists and engineers from several research institutions planned and witnessed the deployment of one of the largest fleets of autonomous vehicles ever deployed in Monterey Bay. The robotic vehicles were programmed to take a range of measurements necessary to assess the causes of ocean change over different timescales. These vehicles allow researchers to observe multiple places at the same time and can be programmed to track down areas undergoing interesting activity such as phytoplankton blooms. They are an integral part of what the future holds for ocean observing and research.

**Read the full article:** annualreport.mbari.org/2017/monterey-bay

The AUV returns from a mission exploring the underside of an iceberg on a calm day in Petersen's Fjord, Greenland. Photo by Erik Trauschke.

ICEBERGS AND ASTEROIDS

# Engineers test vehicles to explore extreme environments

For more than 30 years, MBARI has been developing tools to study life in the extreme and remote environments of the deep sea. Those tools may also prove useful in the US space program as NASA explores other worlds in outer space. In 2017, a team of MBARI engineers contributed to that endeavor as it tested the latest development in autonomous underwater vehicle (AUV) technology among the icebergs of Greenland—proxies for much less accessible asteroids and planets.

During a three-week expedition, MBARI researchers, along with team members from Stanford University, successfully mapped the submerged portions of icebergs using the new AUV. Their goal was to demonstrate a new algorithm that extends this mapping capability to moving targets (for example, icebergs) plus a new software that enables an AUV to fly safely along unknown vertical surfaces such as the side of an iceberg or submarine canyon walls. This expedition was the culmination of a six-year effort funded by NASA's Astrobiology Science and Technology for Exploring Planets program. Whether it's the deep sea or outer space, the steady improvements throughout the history of MBARI's AUV program demonstrate that good engineering has the power to answer some of the biggest questions about our planet and beyond.

**Read the full article**

annualreport.mbari.org/2017/icebergs

These female *Osedax packardorum* worms have long graceful plumes that wave in the ocean currents. Photo by Greg Rouse.

DISCOVERING *OSEDAX*

# Uncovering a world of bone-eating worms on the seafloor

Many fascinating findings at MBARI have resulted from fortunate events of happenstance and serendipity. The chance discovery of a new genus of deep-sea worms living on whale bones led to a 15-year research program to understand how the unusual *Osedax* worms survive in extreme environments. These worms have no eyes, legs, mouths, or stomachs, and they use symbiotic bacteria in their roots to extract fats and oils from the bones. As this research effort came to a close in 2017 MBARI's collection of *Osedax* samples was deposited at Scripps Institution of Oceanography and the Smithsonian Institution so that researchers will have access for further study. Thus, the story of *Osedax* worms will continue to advance.

Close-up of inner workings of a Coastal Profiling Float. Photo by Todd Walsh.

ADVANCING TECHNOLOGY

# Building tools to learn about the many faces of ocean change

The world ocean is undergoing profound changes, particularly in the face of a changing global climate brought on by human activity. Technologies developed by MBARI engineers and scientists, including these three advancements from 2017, often prove invaluable to learning about what a changing ocean means for the life within it and for human society:

- The Coastal Profiling Float, a new autonomous platform specifically designed to measure a range of ocean properties, such as salinity, temperature, pH, oxygen, and nitrate in the continental margins, an area that plays a disproportionate role in the global carbon cycle.
- A coastal upwelling simulator for laboratory experiments that can control for various changing conditions to tease out how animals respond to different factors such as acidity, temperature, and oxygen levels.
- Photo-bioreactors that allow researchers to grow and experiment with algae under predicted future conditions. These photosynthetic microbes are important for uptake of carbon dioxide from the atmosphere and form the base of marine food chains.


A float is deployed from the R/V *Palmer* during the 2016-2017 cruise to the Southern Ocean as part of the NSF-funded SOCCOM project. Image courtesy of SOCCOM.

# The challenge of observing a changing Southern Ocean

The Southern Ocean exerts a major influence on the Earth's climate, serving as a source of nutrients for the rest of the world ocean and absorbing heat and carbon dioxide pumped into the atmosphere by human activities. MBARI researchers are contributing to a large effort to understand the connections between the Southern Ocean, the atmosphere, and the rest of the world ocean.

In a multi-institutional effort, the SOCCOM (Southern Ocean Carbon and Climate Observations and Modeling) science program—funded by the National Science Foundation with additional support by NOAA and NASA—operates an array of profiling floats in the Southern Ocean to measure changing ocean conditions. MBARI developed novel nitrate and pH sensors that are incorporated into more than one hundred of these floats. MBARI also processes the data returned from the floats; the data are publicly available and have been used in dozens of research studies as well as outreach and education activities.

**Read the full article**

annualreport.mbari.org/2017/southern-ocean

The floats have transformed the ability to observe and understand remote ocean regions such as the Southern Ocean, operating year-round, including regions with seasonal ice cover. The information from this project will help provide an understanding of how ocean and atmosphere interactions, far from where most people live, ultimately impact human health and the planet.

# On The Horizon

**Read the full articles:**
annualreport.mbari.org/2017/horizon

Photo by Kim Fulton-Bennett

## Combining sound and light to identify deep swarms of animals

The fields of acoustics and in situ visual observation (now, largely using imaging systems on remotely operated or autonomous vehicles) have made big advances in both technology and application. Yet, they have been used together infrequently. In 2017, MBARI's Acoustical Ocean Ecology Group, with support from the Midwater Ecology Group, began the process of developing integrated acoustical-optical methods using the ROV *Ventana*, making the most of MBARI's longstanding investments and expertise in imaging technologies. The measures of animal communities that can be obtained from acoustics and imaging, used concurrently from a single platform, promise to tell much about life in the ocean and improve the ability to sample it.

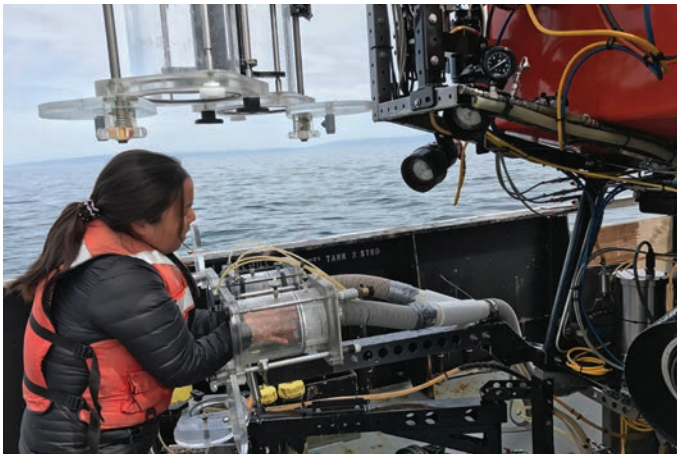


Photo by Susan von Thun

## A new venture for MBARI and the Monterey Bay Aquarium

The Monterey Bay Aquarium and MBARI are combining their unique capabilities to address ocean conservation issues. The new Aquarium-MBARI Incubator Initiative, or AMI$^2$, will develop research projects aimed at fostering science-based policies for ocean health. One important part of this venture is the aquarium's Ocean Memory Lab, where researchers are improving long-term ecological records critical for setting baselines for, and tracking changes in, ocean health. Over the past year, the AMI$^2$ team has turned its attention to themes that center on ocean sampling and observations that bring together the research strengths of both organizations. In 2018, the AMI$^2$ will pair the historically focused sampling approach with new technologies as a way to assess ocean conditions of today. Initial efforts will be centered on the impact of microplastics on marine life and environmental DNA as a way to assess invasive species and the population of certain commercially important fish.

Illustration by Kelly Lance

## Engineering a better way to count and protect rockfish

Just how many fish are in the sea? That's a key question for resource managers trying to determine the health of rockfish off the California Coast. A new seafloor observatory system developed by MBARI in collaboration with The Nature Conservancy will greatly enhance efforts to visually and accurately assess this fishery. In 2017 an MBARI team built and designed a prototype benthic observatory system, which was used successfully for several assessment surveys. In 2018 MBARI will build a more advanced system that will be passed on to a non-profit organization, Marine Applied Research and Exploration, which will operate and maintain the system and conduct rockfish surveys up and down the coast.

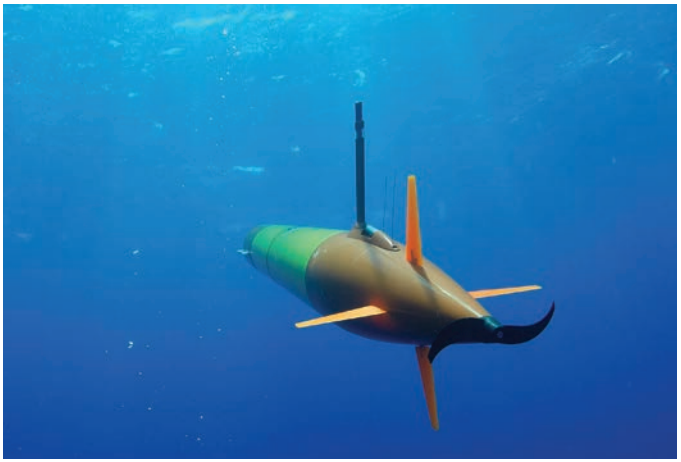


Photo by Elisha Wood-Charlson

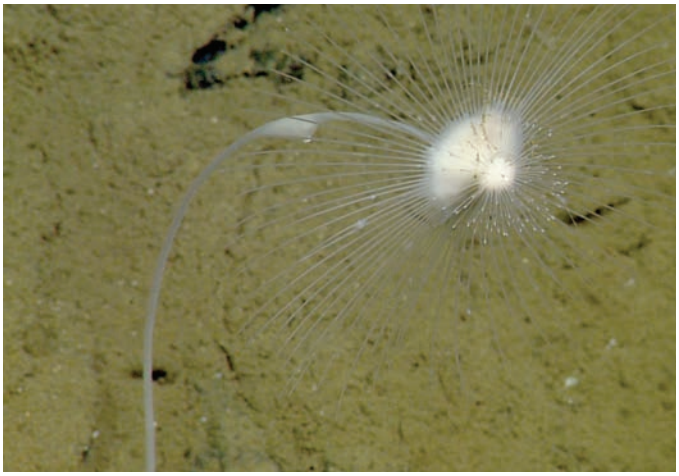
## Collaborations bring distant study sites into reach

Many of MBARI's research efforts are strengthened by collaborating with other teams of researchers, engineers, and institutions. In 2018, three programs will be able to conduct operations not generally within reach of MBARI's vessels by working with the Schmidt Ocean Institute (SOI). SOI will provide its research vessel *Falkor* and its seagoing expertise for MBARI and several collaborators to:

- Deploy autonomous vehicles to sample and characterize ocean eddy ecosystems.
- Conduct remotely operated vehicle dives to gain insight into why white sharks congregate in a certain area of the open Pacific Ocean.
- Revisit a fascinating hydrothermal vent field in Mexico for seafloor mapping and biological investigations.

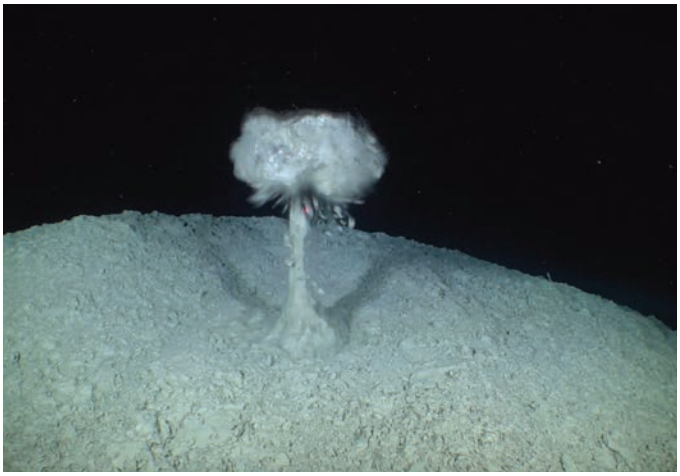
# Weird and Wonderful

**Read the full articles:**
annualreport.mbari.org/2017/weird



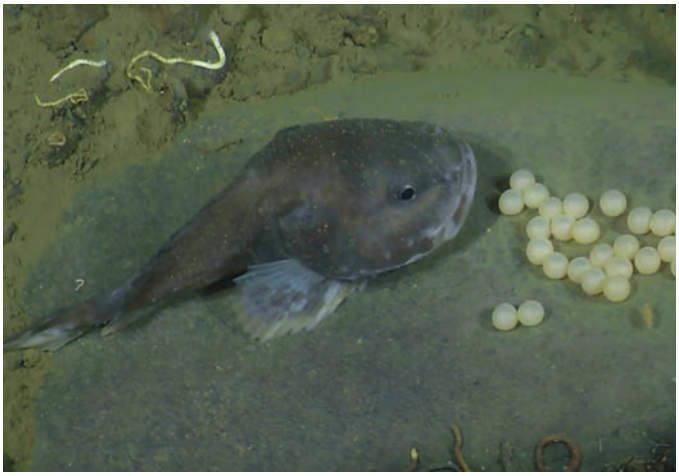
## Delicate-looking sponges prove to be carnivorous

Three new species of parasol-shaped carnivorous sponges were described by MBARI and Canadian colleagues in 2017. Carnivorous sponges ensnare small crustacean prey rather than filtering water, as most sponges do, making them uniquely adapted to the deep-sea habitats where they are found. This trio of sponges, which live in deep water off the coast of California and in the Gulf of California, were named in honor of the scientists who first collected them, including MBARI's Ken Smith (*Cladorhiza kensmithi*) and Carl Hubbs (*C. hubbsi*), as well as the locality where they were collected (*C. mexicana*).



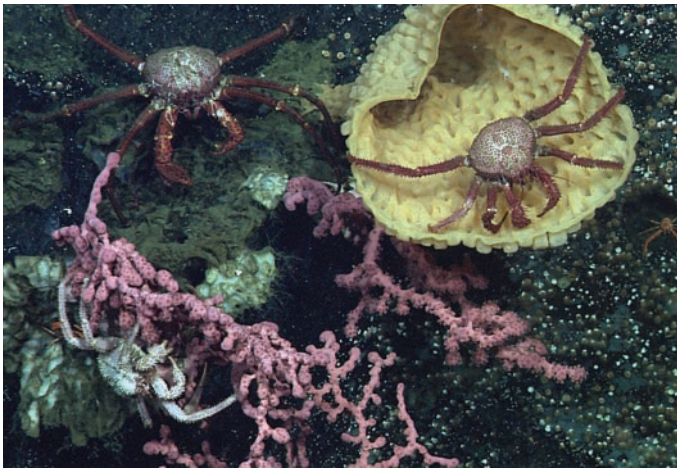
## Capturing an erupting mud volcano on video

While surveying geologic features in the deep sea off Kaohsiung City, Taiwan, an MBARI research team observed bursts of gas emanating from the seafloor near the top of a large mud volcano 425 meters below the ocean surface. Mud volcanoes form when methane gas and highly fluidized mud bubble up onto the seafloor from more than one kilometer beneath the seafloor. Here large methane gas bubbles are observed as explosive events, which disturb and propel the clumps of the mud approximately one meter into the water column. During this expedition, a succession of six explosive gas releases was observed over a period of approximately 17 minutes.



## Brooding blob sculpin in the Canadian Arctic

During a research expedition to the Beaufort Sea in the Canadian Arctic in the summer of 2017, scientists from MBARI, the Korea Polar Research Institute, and the Geological Survey of Canada observed a blob sculpin tending its eggs. The research team was using MBARI's MiniROV to collect samples and document the seafloor using the ROV's high-definition camera. Perched atop a clean rock approximately 1,000 meters deep, the adult fish was standing guard next to small, white spheres: its eggs. This level of parental care has rarely been observed for deep-sea animals. This rare sighting is just another example of how MBARI's early investments in observational technology are paying dividends today.



## New guide catalogs diverse life on deep-sea ridge

Scientists from MBARI and the Monterey Bay National Marine Sanctuary first discovered a rich ecosystem at Sur Ridge, off the coast of Big Sur, in 2013. The researchers have revisited Sur Ridge five times to better understand the vibrant sponges and corals they have observed. But sponges and corals are not all they have found. MBARI and sanctuary researchers combed through video collected by ROV *Doc Ricketts* and in 2017, they published the *Sur Ridge Field Guide*—available online—that includes at least 261 species of animals observed at Sur Ridge. The guide is an inventory of benthic and midwater organisms, and associated imagery, that provides a baseline taxonomic characterization. The field guide provides a quick source of information for researchers and insight into the interrelationships between the animals in this habitat.

# Awards

## Kelly Benoit-Bird

**Elected Fellow**

Acoustical Society of America

## Peter Brewer

**Award for International Scientific Cooperation**

Chinese Academy of Sciences

## Francisco Chavez

**International Recognition Award, Mexican Carbon Program**

National Ocean Partnership Program Excellence in Partnering Award

## Bill Kirkwood

**Service Award**

Institute of Electrical and Electronics Engineers/Oceanic Engineering Safety

## Monique Messié

**Marie Curie Fellowship**

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MBARI

Funded by the David and Lucile Packard Foundation, the Monterey Bay Aquarium Research Institute is a private non-profit research center that conducts fundamental research and technology development in the ocean sciences. The overarching goals of MBARI are to develop innovative technologies for exploring and understanding the ocean and sharing the knowledge and solutions gained with the global marine science and conservation community as well as the general public.

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