Research and Development: Science and Engineering Project Highlights

Jim Barry (PI)
An upwelling simulator for experimental studies

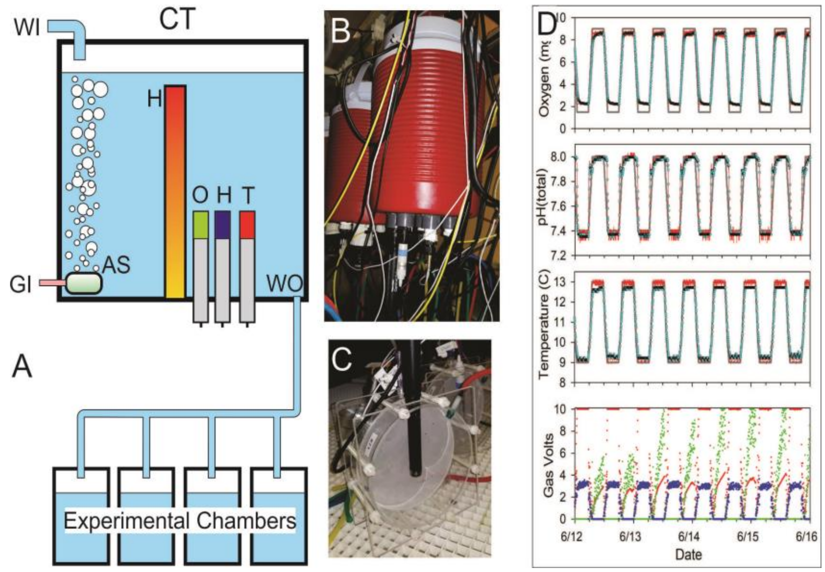
Red abalone (left) and the "abalone king" (right) in Monterey amidst his spoils circa 1910. Abalone are affected by coastal upwelling.

Coastal upwelling is well known for its role in stimulating primary productivity by drawing deep, nutrient-rich waters to the surface, thereby higher trophic levels in the California Current Large Marine Ecosystem. The lesser-known, perhaps "dark" side of coastal upwelling is that upwelled waters may cause problems for some marine species. Nitrate and other nutrients are regenerated at depth by the microbial oxidation of sinking organic debris, a process that consumes oxygen and produces carbon dioxide, generating the low-oxygen, low-pH conditions typical in the oxygen minimum zone (OMZ). In the past decade or so, improved measurements of coastal conditions (in part by MBARI) have revealed wide fluctuations in temperature, oxygen, and pH levels in various inshore areas, including those influenced by upwelling. While this may be a windfall for phytoplankton, exposure to hypoxic, somewhat corrosive conditions can be stressful or lethal for many animals. Recent studies have shown that abalone and other coastal species exposed to upwelling conditions can have lower growth rates, weaker calcification, and other effect compared to milder sites.

Climate projections indicate coastal upwelling to become more frequent and prolonged in the future, and upwelled waters will likely be even lower in oxygen and pH due to shoaling of the OMZ. What can we expect for the future health of species and communities in the California Current Ecosystem? Are upwelling conditions along the coast today stressful for some species? What will happen as upwelling conditions become more extreme? To address such questions we have developed an aquarium control system (Upwelling Simulator, or UpSys) capable of tight control of dissolved oxygen (DO), pH, and temperature (T) in aquaria, to enable laboratory experiments measuring how and why coastal species respond to upwelling.

Most studies on the influence of ocean acidification or related changes in ocean conditions on species typically have not considered the effects of environmental variability, even though most habitats are highly variable. We know from nearshore sensors that upwelled waters vary over tidal time scale (12, 24 h) and can "arrive" quickly, cooling of 3 ^{o}C, -0.5 pH units, and -6 µmol kg^{-1} O_2 within 30-90 minutes. To realistically mimic ocean variability, the UpSys must be capable of the same scope of changes in seawater tanks over as little as 30 minutes.

The UpSys can simultaneously control conditions in 15 “conditioning” tanks (CT), each programmed with a user-defined schedule of variation in conditions; each CT then delivers water to several smaller “experimental” chambers (EC) where animals are exposed. With such flexibility, researchers can simulate current and future upwelling scenarios in several tanks, as well as intermediate levels, and then compare the performance of animals among treatments. In addition, the Upsys can be used to disentangle the relative roles of changing pH, DO, and T. For example, upwelling typically brings cold, low oxygen, low pH water to the coast. The UpSys can simulate typical upwelling events, as well as events in which water remains warm, or with high pH or high oxygen to evaluate the role of each factor. We are currently investigating the influence of upwelling on various life stages of red abalone, a key coastal species along this coast.



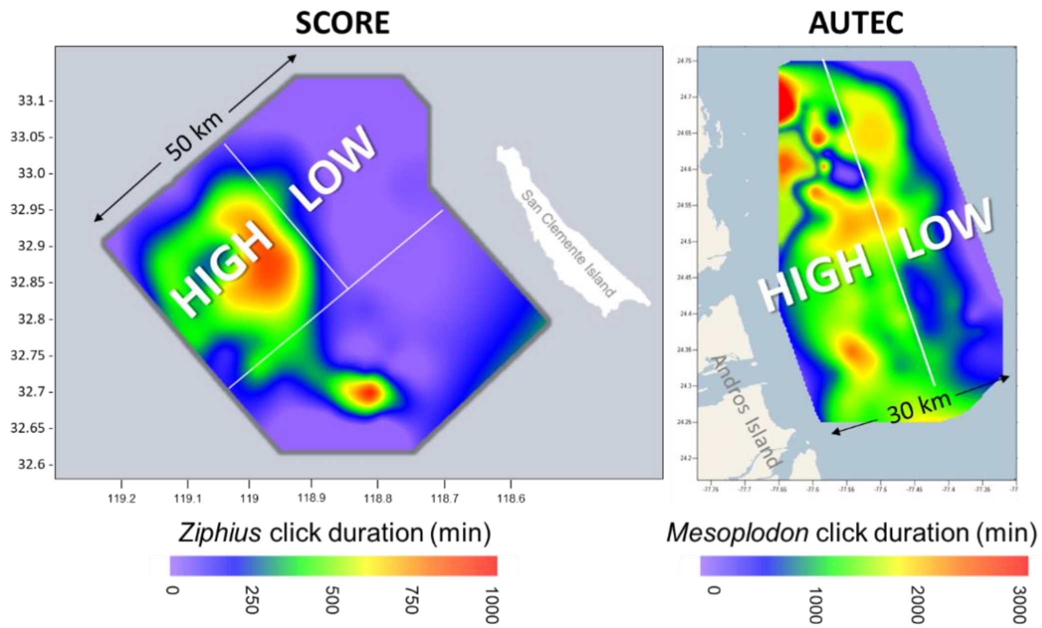
A. UpSys design: O2, pH, and temperature are regulated in a conditioning tank (CT and B) and water is delivered by gravity to experimental chambers (C). D. Performance of UpSys over four days, showing Set Points (gray lines, CT values (red) and exp. chamber values (light blue). Bottom graph shows gas flow values for N2 (red), O2 (green) and CO2 (blue) EA.

Recent publication

- O’Leary, J., Barry, J.P., Gabrielson, P., Rogers-Bennet, L., Potts, D., Palumbi, S., Micheli, F. (2017). Calcifying algae maintain settlement cues to larval abalone following algal exposure to extreme ocean acidification. *Scientific Reports* 7, Art. 5774. Doi:10.1038/s41598-017-05502-x

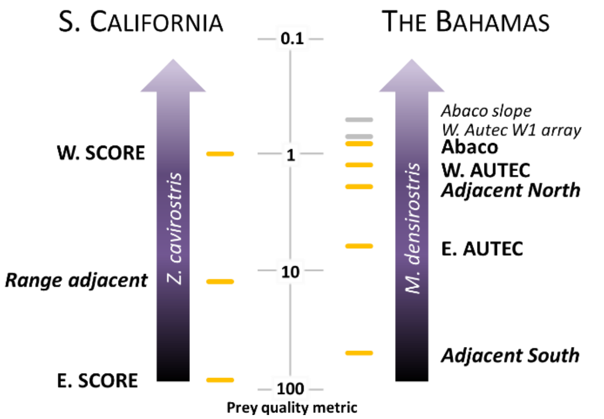
Kelly Benoit-Bird (PI)
Protecting Beaked Whales: A Tale of Two Naval Ranges

Mortal stranding events of individuals of several species of beaked whale have been documented in recent decades in association with Navy mid-frequency (1-10 kHz) active sonar (MFAS). These events fueled substantial research interest in these taxa over the past several decades and have made them a management priority, particularly with regard to military sonar systems. However, mass strandings do not occur during most sonar operations. Rather, some beaked whales have been observed avoiding MFAS operations by abandoning known foraging areas on sonar ranges, returning once disturbances abate.



The observed habitat use by beaked whales was measured using acoustic detections of foraging animals in two different US Navy testing ranges, SCORE off Southern California and AUTEC in the Bahamas. They show remarkable variation over spatial scales that are small relative to the swimming capabilities of the animals.

Energy is the currency of survival for free-ranging animals. As a result, approaches to understand the flow of energy in an individual, population, and ecosystem are key tools in both understanding ecosystem function and developing appropriate management. As beaked whale interactions with human activities have become increasingly recognized, compliance with the Marine Mammal Protection Act which designates the unit of protection as the stock or populations has necessitated the use of energy models to link behavior with demographic outcomes. Not surprisingly, these models have identified energy intake as a key limiting factor. However, this factor has largely been treated qualitatively, as "habitat quality" that is scored and is rarely linked with any direct data on prey or environment. We have been working with the US Navy to fill this critical gap by obtaining direct measures of beaked whale prey resources on two different testing ranges, areas where interactions between MFAS and beaked whales are particularly intense.



A comparison of a beaked whale prey quality metric estimated for regions within and adjacent to two US Navy test ranges provides insight into the factors driving the observed habitat usage by these animals as well as the consequences of disturbance.

Our data provide the first quantitative assessments of prey resources for beaked whales. We integrated these prey measures with our growing understanding of the biology of these cryptic animals to provide a quantitative metric of their foraging habitat. We used this metric to estimate foraging and energetic consequences of decisions made by animals in different foraging habitats as well as to inform models on the effects of human disturbance on energy gains. This approach provides a quantitative framework for incorporating a large number of prey metrics into a single measure that is related directly to the biological characteristics of the predator. The metric we developed is adaptable to different prey conditions and prey types and accounts for differences in the size, behavior, and diet of the predator, facilitating comparative research across areas, ecosystems, and species. In using this metric to make comparisons across areas and ecosystems, we learned that the single largest determinant of beaked whale habitat choice is the fine scale distribution of squid—prey "hot spots" drive foraging choices. This environmental heterogeneity affects the energetic consequences of disturbance and/or avoidance of different habitat areas, resulting in very different implications for management decisions for these protected species. While beaked whales serve as the model here, the overall approach yields a biologically meaningful, comparative framework for quantifying the consequences of management decisions in the deep sea.

Recent Professional Activities

- Source, Speaker, and Featured Scientist for "Unseen Oceans" special exhibit at American Museum of Natural History to open Mar 2018
- Editorial Board, *Limnology and Oceanography*, Jan 2018-Present
- Session Organizer and Co-Chair, Ocean Sciences Meeting 2018, Jun 2017-Present
- Ocean Noise Leadership Team, Consortium for Ocean Leadership, Nov 2016-Preseent
- IEEE Oceanic Engineering Society Technical Committee on Underwater Acoustics, Jan 2006-Present
- Acoustical Society of America Animal Bioacoustics Technical Committee, Dec 2002-Dec 2004, May 2005-May 2008, Dec 2016-Present

Recent Publication

- Sato, M.* & Benoit-Bird, K.J. (2017). Spatial variability of deep scattering layers shapes the Bahamian mesopelagic ecosystem, *Marine Ecology Progress Series*, 580:69-82.

Jim Birch and Chris Scholin (PI)
Being there is everything: MBARI on the trail of "brain-eating amoebae

Near Yellowstone National Park, at the junction of the Gardner and Boiling Rivers in Montana, visitors create small weirs and soak in the resultant pools. It is within these pools that Senior Research Technician Roman Marin III (right) used a third-generation Environmental Sample Processor to collect water in search of the brain-eating amoeba, Naegleria fowleri. *Images: Kevan Yamahara.*

As MBARI technologies evolve over the years, they often make impacts in ways never envisioned at their outset. In 2017, one of MBARI's instruments for detecting microscopic organisms in the ocean was put to a new use aimed at protecting human health far from the sea. The Environmental Sample Processor (ESP) was tested to see if it could reveal tiny amoebae that live naturally in warm waters and can cause serious brain damage in humans.

The ESP has been successfully deployed in coastal, deep-sea, and open-ocean environments, demonstrating its ability to detect a wide range of organisms and substances they produce.

Along the way, the device attracted attention from groups who are charged with oversight of our nation's freshwater resources (lakes, rivers, reservoirs). They too have a need to collect samples of water, sometimes from remote places, and apply biomedical-type tests for public health protection and resource management purposes. After a chance meeting of MBARI's ESP group and representatives from the US Geological Survey (USGS), question arose whether the instrument could be used to monitor streams for pathogens and invasive species, in particular a tiny amoeba, *Naegleria fowleri*, commonly called the "brain-eating amoeba." It is found in warm-to-hot bodies of freshwater around the world. If you get water harboring *N. fowleri* up your nose, there is a chance the amoebae will migrate up your sinus nerve and into your brain, where they begin consuming nerve cells; the fatality rate is 97 percent. Fortunately, even though *Naegleria* amoebae are common, brain infections are very rare.

For MBARI researchers Kevan Yamahara and Roman Marin it became a unique opportunity to test out the water-sampling capabilities of the ESP in the wild near Yellowstone National Park. The results: Yes, the ESP can capture *Naegleria fowleri* and also environmental DNA (eDNA)—genetic material that is released by organisms into their surroundings through natural processes, such as excretion as well as the shedding of skin cells, etc. The analysis of eDNA offers a new way to detect the presence of invasive organisms or larger animals, such as highly managed species, which have important implications for humans and wildlife alike (as an aside, eDNA analyses are being widely applied in marine systems, e.g., NOAA's Marine Biodiversity Observation Network program: http://sanctuaries.marinebon.org/). Preliminary results from the river tests are encouraging, and so plans are now being made for more rigorous testing this coming summer pending funding approval from the USGS's Ecosystems Mission Area Invasive Species Program. In addition to *Naegleria*, our targets will be zebra and quagga mussels, and New Zealand mud snails to name a few. Managed fish species will also likely make the list. Exploring the use of eDNA technology for tracking salmonids (etc.) in California coastal streams is also one cornerstone of a new project with the Monterey Bay Aquarium (Kyle Van Houtan/Scholin—the Aquarium/MBARI Incubator Initiative—the AMI^2 project).

The 2017 "Yellowstone experiment" was a joint effort with the USGS and Montana State University funded by a USGS Innovation Center grant (ironically, a program initiated by Marcia McNutt when she oversaw the USGS). In parallel, the USGS is collaborating with the US Centers for Disease Control and Prevention (CDC) to develop standardized testing methods to detect and quantitate *N. fowleri*. That effort dovetails with a larger initiative to place automated water-monitoring systems around the country. This pilot project was the first in what we expect will be a series of tests to determine if the ESP or devices of that ilk can be used by the USGS to improve monitoring of waters across the United States by instrumenting the national stream gage network with genetic detection systems.

Peter Brewer (Senior Adjunct)

On January 23, 2018, Peter Brewer received the Award for International Scientific Cooperation from the Chinese Academy of Sciences (CAS). Peter is pictured below with CAS President Bai Chunli (second to the left), who presented the award to Peter at the ceremony at the new CAS University campus in China, along with fellow recipients David Neely of the Rutherford Appleton Laboratory and Yimei Zhu of the Brookhaven National Laboratory.

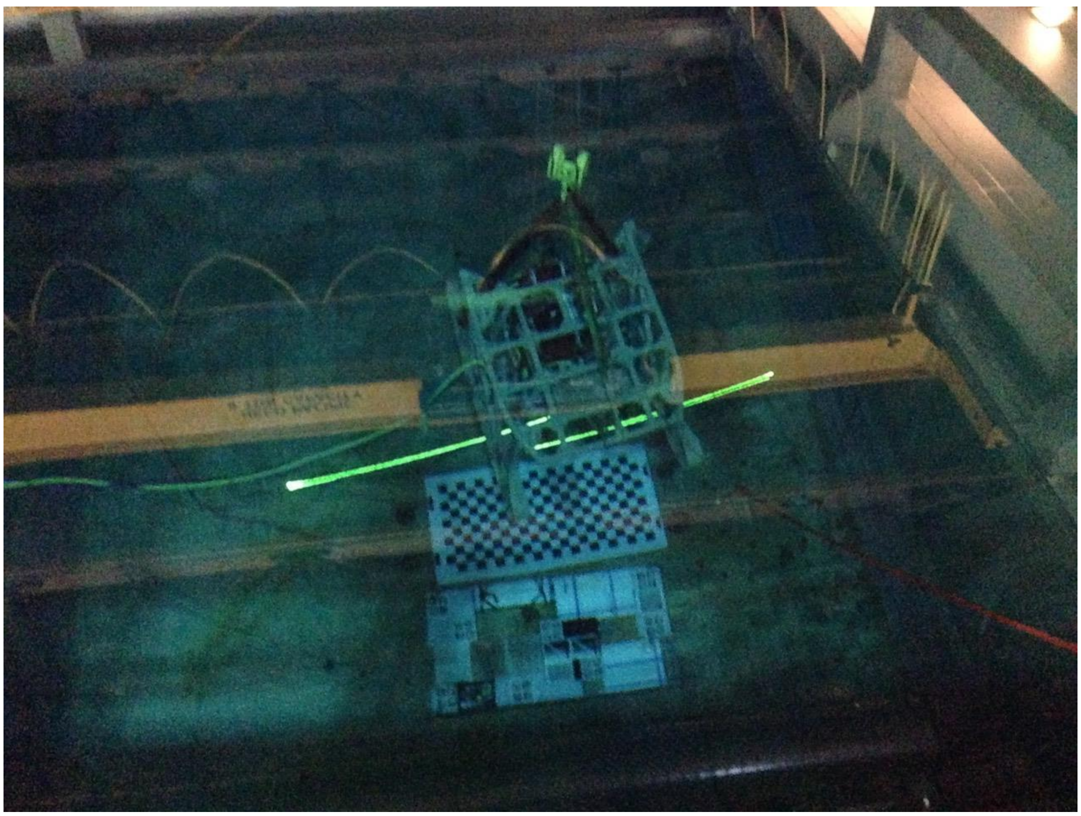
The award, launched in 2007, honors top foreign talents who have been in long-term collaboration with CAS and have made major achievements including outstanding contributions to key technological breakthroughs. Peter has worked closely with CAS for more than 10 years, providing critical support to the design, testing, and scientific application of R/V *Kexue* and ROV *Faxian*, and has led the academy's research in the application of deep-sea sciences. In addition, Peter participated in Project Western Pacific Ocean System (WPOS), providing valuable guidance and assistance to core tasks including exploratory research of deep-sea hydrothermal vents, cold seeps, and seamounts, as well as independent R&D of large facilities for deep-sea detection and sampling. These achievements could not have been made possible without Zhang Xin, Ed Peltzer, Peter Walz, and Bill Kirkwood.

In addition to his contributions to the cultivation of doctoral students in China, Peter has also created many opportunities for early-career CAS scientists to join different US deep-sea detection cruises, helping them advance on to world-class research platforms. The cooperation between Peter and CAS has greatly boosted the development of China's deep-sea sciences and equipment systems, a milestone contribution to the development of China's marine sciences.

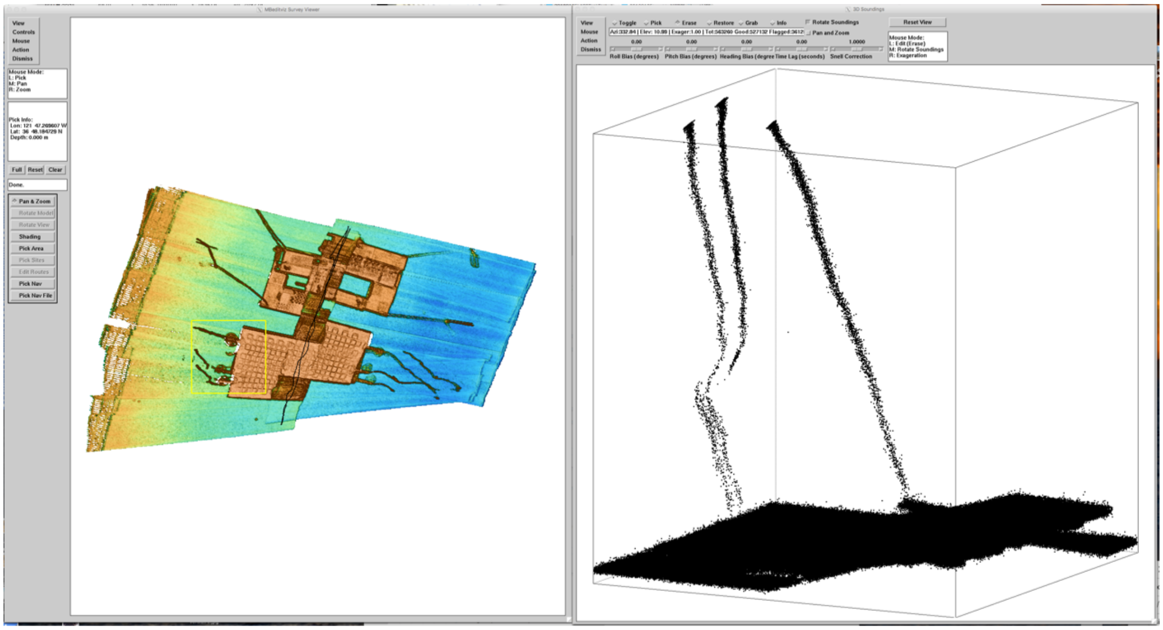
David Caress
Ocean Imaging

The Ocean Imaging project team is developing a low-altitude seafloor survey capability combining subsea lidar, multibeam sonar, stereo color cameras, and an inertial navigation system in order to achieve one-centimeter-scale topographic mapping combined with color photomosaics. MBARI took delivery of a new wide swath subsea lidar (WiSSL) system from 3D at Depth in December 2017. The WiSSL achieves a wider field of view and faster scan rate than the lidar used previously, allowing us to more than double the coverage of our ROV-based one-centimeterm-resolution seafloor surveys.

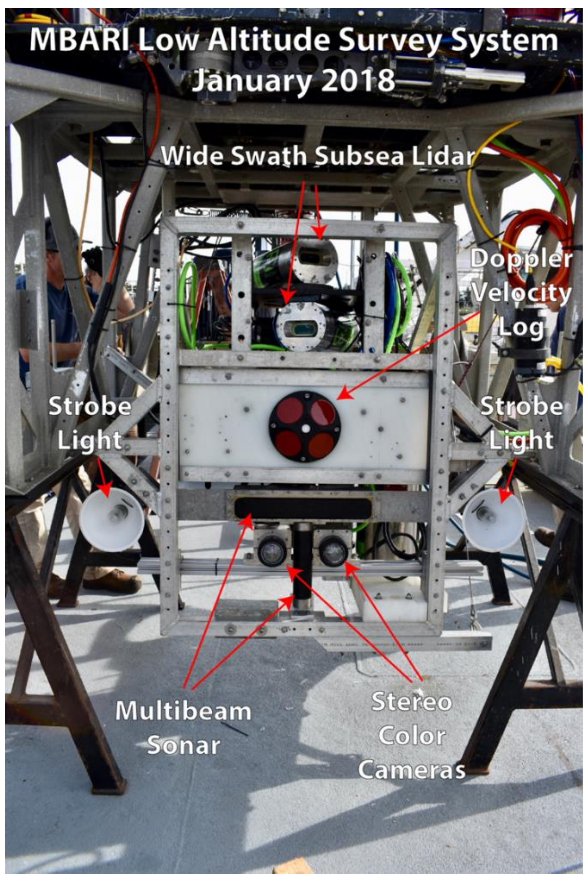
We just completed the first sea trials of the 2018 low-altitude survey system integrated with ROV *Ventana*, successfully demonstrating the lidar performance at 1,500 meters depth. The current survey system includes an articulating mount for the sensor package within a *Ventana* toolsled, allowing surveys of steep terrain. In addition to testing the mapping sensors, we also successfully demonstrated automatically articulating the survey system to be normal to the seafloor, and automated survey line running using *Ventana's* new Greensea control software.



The low altitude survey system mounted in a Ventana *toolsled surveying across test structures in the test tank, with the lidar scan visible.*



Lidar mapping of the test structures and tag lines in the test tank in map view (left) and 3D point cloud (right).

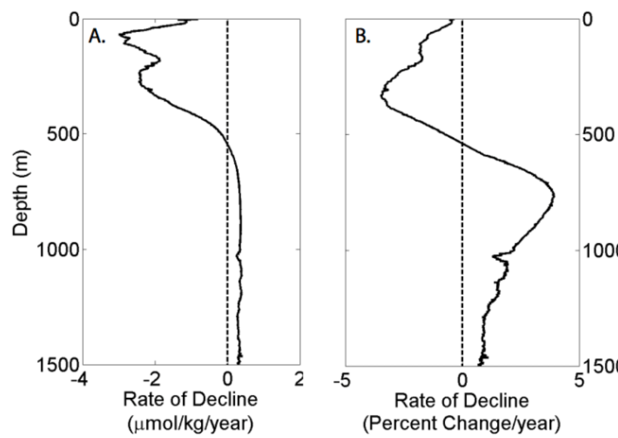


Bottom of mapping system on ROV Ventana *with the mount rotated all the way forward, as if mapping a vertical wall.*

Francisco Chavez (PI)
Biological Oceanography Group

In a recent paper in *Science*, Breitburg et al. discuss ***declining oxygen in the global ocean and coastal waters.*** Oxygen concentrations in the ocean have been declining since the middle of the 20th century. This oxygen loss—or deoxygenation—is one of the most important changes occurring in an ocean increasingly modified by human activities. Oxygen is fundamental to biological and biogeochemical processes in the ocean and its decline can cause major changes in ocean productivity, biodiversity, and biogeochemical cycles. Analyses indicate that oxygen minimum zones in the open ocean have expanded by several million km^2 and that hundreds of coastal sites now have oxygen concentrations low enough to limit the distribution and abundance of animals. In the open ocean, a warming world is considered the primary cause of ongoing deoxygenation. Numerical models project further oxygen declines during the 21st century even with ambitious emission reductions. Increasing global temperatures decrease oxygen solubility in water, increase the rate of oxygen consumption via respiration, and are predicted to reduce the introduction of oxygen from the atmosphere and surface waters into the ocean interior by increasing stratification and weakening ocean overturning circulation.

In estuaries and other coastal systems, oxygen declines have been caused by increased loadings of nitrogen, phosphorus, and organic matter, primarily from agriculture, sewage, and the combustion of fossil fuels. An important paradox to consider in predicting large-scale effects of future deoxygenation is that high productivity in nutrient-enriched coastal upwelling areas associated with oxygen minimum zones also supports some of the world's most productive fisheries.



Vertical profiles of the (A) absolute and (B) percent rate of oxygen change for the Monterey Bay region over 1998 to 2013. Above ~500 meters oxygen levels have decreased notably with a shallow peak at 50-100 meters, near the base of the thermocline and a deeper peak, centered around 300 meters. Beneath ~500 meters in the oxygen minimum and below, levels appear to have increased slightly over the same time period.

Predicting deoxygenation-induced changes in ecosystem services and human welfare requires scaling effects that are measured on individual organisms to populations, food webs, and fisheries stocks, considering combined effects of deoxygenation and other ocean stressors, and increased research emphasis in developing nations. Reducing effects of other stressors may provide some protection to species negatively affected by low oxygen conditions. Ultimately, though, limiting deoxygenation and its negative effects requires a dramatic shift in our business as usual way of managing planetary metabolism.

Breitburg, D., L A. Levin, A. Oschlies, M. Grégoire, F. P. Chavez and 12 others (2018). Declining oxygen in the global ocean and coastal waters, *Science*, doi:10.1126/science.aam7240.

Awards and Service

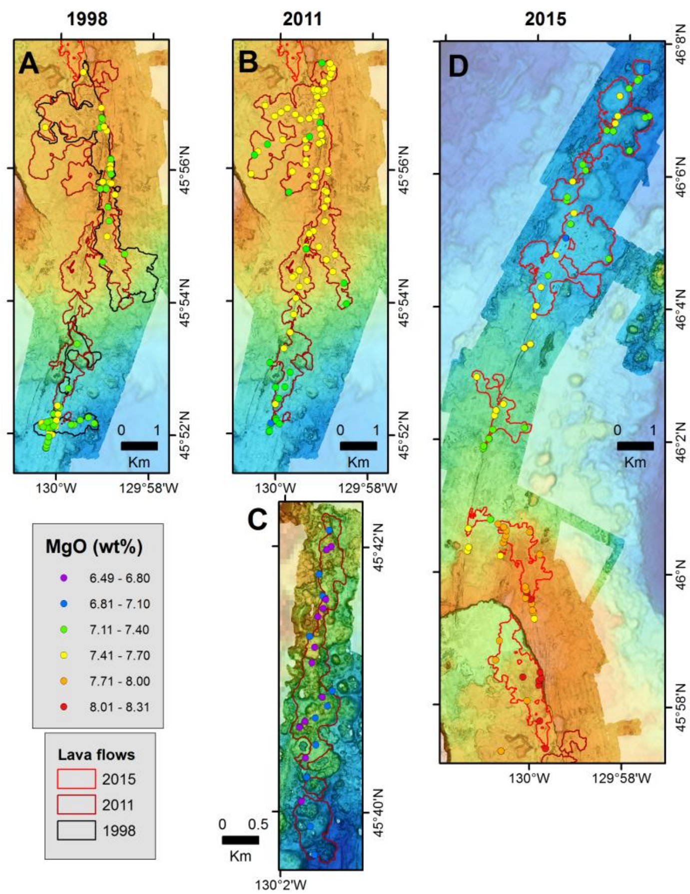
- Programme Board, Group for Earth Observations (GEO), 2016-Present
- Blue Planet Steering Committee, 2016-Present
- Scientific steering committee for Global Ocean Oxygen NEtwork (GO_2NE), 2016-Present
- National Ocean Partnership Program Excellence in Partnering Award, 2017
- Recognized by the Mexican Carbon Program for Chavez's scientific trajectory and invaluable collaboration between Mexico and USA in relation to knowledge of carbon dynamics in marine ecosystems.
- Advisory Council for the Consorcio de Investigación del Golfo de México – CIGoM, 2017-Present
- Director, Central and Northern California Ocean Observing System, Feb 2017-Jan 2018).

Recent Publication

- Pennington, J.T. and F.P Chavez (2017). Decade-scale oceanographic fluctuation in Monterey Bay, California, 1989-2011. *Deep-Sea Research Part II,* doi: 10.1016/j.dsr2.2017.07.005.

Dave Clague (PI)
Submarine volcanism

We have continued writing up work on Axial Seamount derived from our previous AUV mapping surveys and ROV dives. A paper published online compares the 1998, 2011, and 2015 flows, fissures, and other morphological changes observed in the mapping and dives. A paper in preparation is about the distribution and chemical variability of lavas from the three eruptions. The chemical variations within and between the three eruptions are illustrated in the attached figure. The compositions of the near-summit eruptions in 1998 and 2011 are within analytical precision and show that 13 years between eruptions is a steady state for the magma chamber with addition of new hotter magma balanced by cooling during the 13 years between eruptions. Lava temperatures can be calculated from the magnesium content of the volcanic glasses, and yield maximum temperatures for the two eruptions of ~1,188°C. In contrast, the 2015 eruption is hotter (~1,200°C), reflecting the short interval between the 2011 and 2015 eruptions that limited cooling of the system. We can also calculate that 2011 magma transported down the south rift in an underground dike cooled about 17°C as it migrated about 30 km, and that 2015 magma transported down the north rift in an underground dike cooled about 23°C as it migrated only about 20 km. This factor of two differences in magma cooling rates suggests that the 2015 north rift dike traversed shallower, cooler country rocks than the 2011 dike down the south rift.



Maps of the 1998 (A), 2011 (B and C) and 2015 (D) flows erupted at Axial Seamount with lava samples identified by their MgO contents. All but a few of the AUV mapping surveys were completed using MBARI mapping AUVs and the majority of the lava samples collected were collected by MBARI ROVs.

Another paper in preparation is about the summit deformation of Axial Seamount as the volcano discharges magma during eruptions and accumulates magma in between eruptions. A set of surveys to repeat the pattern established by our AUV was done this summer by the AUV *Sentry*. Precise alignment of the maps in post-processing with MB-System software allows year-to-year vertical changes of the volcano over a wide area of the edifice to be detected, and shows that Axial is inflating again toward the next eruption.

The high-temperature lavas erupted in the summit caldera in 2015 are the first time in more than 350 years that such hot magmas erupted near the summit of Axial. This, combined with the rapid rate of magma recharge since the 2015 eruption, suggests that Axial may have entered a new period of activity with shorter intervals between hotter eruptions producing more fluid lava flows. The next eruption may be as soon as 2020-2021.

Professional activities

- Revised and resubmitted: Clague, D.A., D.W. Caress, D.M. Dreyer, L. Lundsten, J.B. Paduan, R.A. Portner, R. Spelz-Madero, J.A. Bowles, P.R. Castillo, R. Guardado-France, M. Le Saout, J.F. Martin, M.A. Santa Rosa-del Río, R.A. Zierenberg (2018). Geology of the Alarcon Rise, Southern Gulf of California, *Geochemistry, Geophysics, and Geosystems* (resubmitted after minor revisions)
- Jenny Paduan is the lead writing and preparing a manuscript for submission: Paduan, J.B., D.W. Caress, D.A. Clague, R. Spelz-Madero, J.F. Martin, M. Lilley, L. Lundsten, J. Lupton, F. Neumann, M. Santa Rosa-del Rio, G. Troni, G. Wheat, R.A. Zierenberg, Discovery of Hydrothermal Vent Fields on Alarcón Rise, in Pescadero Basin, and on the Adjacent Transform Fault Zones, Gulf of California (nearing completion to be submitted to *Geochemistry, Geophysics, Geosystems*).
- Dave Clague is the lead writing a new manuscript on the compositional variations of the historical lava flows erupted in 1998, 2011, and 2015 on Axial Seamount.
- Dave Caress is the lead assembling a manuscript presenting the changes in seafloor elevation near the summit of Axial Seamount as magma accumulates between eruptions and is discharged during eruptions in 2011 and 2015. This manuscript will include changes during periods before the 2011 eruption, between the 2011 and 2015 eruptions, and since the 2015 eruption.
- Sasha Belinsky continues to clean up loose ends concerning the curation of rock samples sent to the Smithsonian, the US Geological Survey, and a number of collaborators.

Publications

- Clague, D.A., K.M. Marsaglia, B.L. Cousens, J.B. Paduan (2018). Oligocene and Miocene volcanics in sedimentary forearc of the Outer Continental Borderland, SEPM Special Paper, published online.
- Clague, D.A., J.B. Paduan, D.W. Caress, W.W. Chadwick Jr., M. Le Saout, B. Dreyer, R.A. Portner (2018). High-resolution AUV mapping and targeted ROV observations of three historical lava flows at Axial Seamount, *Oceanography* (MBARI 30th anniversary issue), published online.

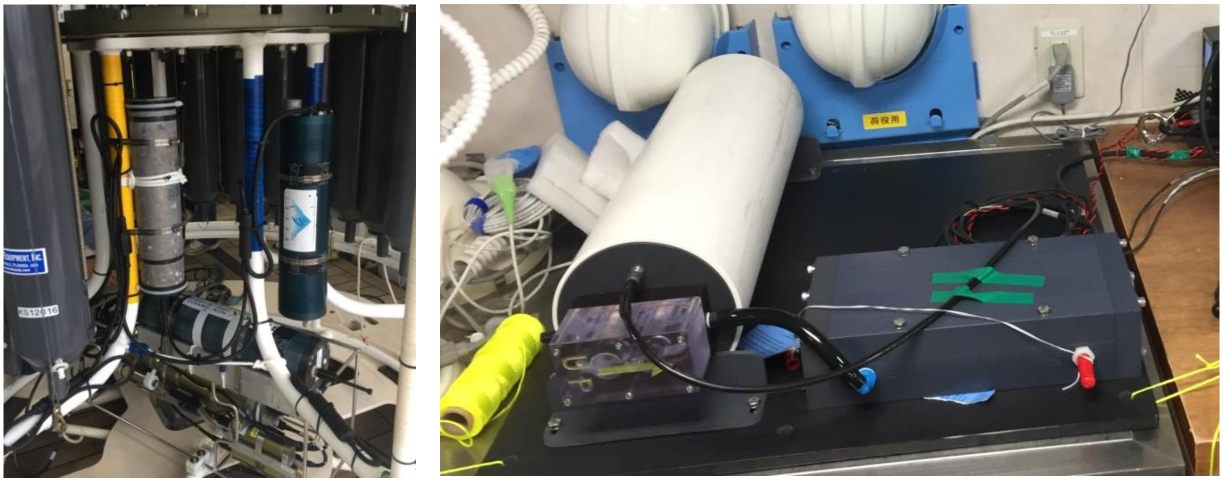
Andrea Fassbender & Yui Takeshita (PIs)
Sampling the swaying seas of the Kuroshio

From January 18 to 30 of 2018, Yui and Andrea participated in a Japanese research cruise aboard the R/V *Shinsei Maru* to study ocean biogeochemistry in the mode water formation region of the western North Pacific Ocean. This collaboration with colleagues from the Japan Agency for Marine Science and Technology (JAMSTEC), University of Tokyo, Tohoku University, and Kaiyo University came about through an effort to coordinate international physical and chemical oceanographic research related to western boundary current (WBC) processes. Much of the planning for this cruise occurred during the Ocean Carbon Hot Spots workshop hosted at MBARI by Andrea Fassbender and Stuart Bishop in September 2017.

The Kuroshio is the WBC of the North Pacific Ocean, just as the Gulf Stream is for the North Atlantic. Equatorward of all WBCs are regions of intense winter mixing where the ocean becomes homogenous to depths of ~200 to >1,000 m. Subsequent warming during spring causes the water column to thermally stratify, isolating the shallowing surface layer from the deeper waters they were connected to during winter. Biological activity near the surface ocean alters the chemical properties of the water, while the deeper waters remain homogeneous, reflecting conditions from the prior winter mixing. These waters are called mode waters, because they create a thick layer of water with the same properties. WBCs exhibit some of the highest air-to-sea carbon dioxide fluxes in the global ocean; therefore, deep wintertime mixing provides a pathway for carbon to enter the ocean interior. Dispersion of these mode waters throughout the North Pacific Ocean isolates this carbon from contact with the atmosphere on decadal time scales, representing an important anthropogenic carbon sink. Due to these characteristics, WBC regions are unique places to study both natural, biological carbon cycling as well as anthropogenic carbon uptake and storage processes.

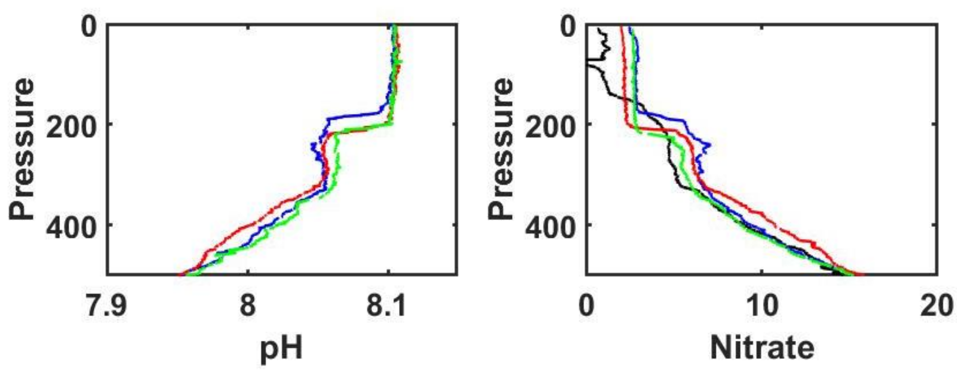
During the cruise, Yui and Andrea were responsible for measuring carbon dioxide parameters and dissolved inorganic carbon parameters. With the help of Ken Johnson and his team, we were able to outfit the rosette with autonomous sensors for pH (DeepSea Durafet) and nitrate (ISUS) to profile the water column during CTD casts. We also borrowed the Johnson Lab spectrophotometer to analyze discrete water samples collected during CTD casts for pH to validate with the much higher resolution autonomous sensor measurements. Water samples were also collected for later analysis of dissolved inorganic carbon and total alkalinity to be conducted at MBARI in our joint lab. In addition to vertical water column sampling, Yui tested a new prototype system, the BioGeoChemistry Surface Underway MBARI Observing-system (BGC-SUMO) for continuous measurement of surface pH and nitrate.

With all sensors functioning as planned, we set sail toward the National Oceanographic and Atmospheric Administration's Kuroshio Extension Observatory (KEO) buoy, where we would complete a 50x50 km box pattern around the mooring. The plan was to collect samples at each



(left) MBARI developed pH (Deep-Sea-Durafet) and nitrate (ISUS) sensors equipped on the CTD rosette for one-meter resolution profiles. (right) Prototype BGC-SUMO that maps high-resolution surface biogeochemistry.

corner of the box before deploying a glider, biogeochemical float, and microstructure float for continuous monitoring through late April when the recovery cruise will take place. Unfortunately, before we could complete the box and make the final cast, a treacherous storm imposed on our plans and we had to return to port. While in port, Tokyo experienced the coldest temperatures and highest snowfall on record for the past 50 years! One member of the cruise science team from South America saw snow for the first time and numerous scientists and students played soccer in the snow in the JAMSTEC parking lot. Once the storm moved through Tokyo, out to KEO, and beyond, we set course to return to our study site to conduct one more CTD cast and deploy the autonomous assets. A subsequent storm thwarted this plan as well, and we were forced to conduct our last CTD cast and deploy the autonomous assets a few degrees northwest of KEO.



Profiles of pH and nitrate from the autonomous sensors. The stations were located within 50 km of each other, yet show very different water column properties despite similar surface conditions. This highlights the importance of studying sub-mesoscale variability (< 100 km) with high vertical resolution using autonomous vehicles and technology.

Nitrate profiles collected during the cruise will be used for comparison with the biogeochemical profiling float nitrate sensor. Discrete observations (including carbon) will also be used to develop regional relationships between oxygen, nitrate, temperature, and salinity with dissolved inorganic carbon, pH, and total alkalinity. These relationships will be compared to existing global-scale algorithms and will be applied to glider data to map three-dimensional fields of carbon and nutrients during the spring transition as the mixed layer shoals. Participation in this cruise helped solidify a new international relationship, and all scientists aboard the *R/V Shinsei Maru* look forward to continuing this collaboration into the future.

Takeshita and Fassbender Joint Professional Activities

- Research Technician hiring committees for our respective laboratories (November–January)
- Research cruise aboard the *R/V Shinsei Maru* (January)
- Co-chairs of 2018 Ocean Sciences Session (February): *Spatial and Temporal Variability of Seawater Chemistry in Coastal Ecosystems in the Context of Global Change*, Portland, OR, February 12-16, 2018.
- Topic editors for a special issue in the journal *Frontiers* on Spatial and Temporal Variability of Seawater Chemistry in Coastal Ecosystems in the Context of Global Change (February–June)

Fassbender Recent and Forthcoming Professional Activities

- Co-guest editor of joint US CLIVAR Variations and OCB News edition (October) and coauthor on the following contributions:
  - Rodgers, K.B., Zhai, P., Iudicone, D., Aumont, O., Carter, B., Fassbender, A.J., Griffies, S.M., Plancherel, Y., Resplandy, L., Slater, R.D., and K. Toyama. Western boundary currents as conduits for the ejection of anthropogenic carbon from the thermocline. Joint US CLIVAR Variations and OCB News edition entitled *Frontiers in western boundary current research,* November, 2017.
  - Zhang, D., Cronin, M.F., Lin, X., Inoue, R., Fassbender, A.J., Bishop, S.P., and A.J., Sutton. Observing air-sea interaction in the western boundary currents and their extension regions: Considerations for OceanObs 2019. Joint US CLIVAR Variations and OCB News edition entitled *Frontiers in western boundary current research,* November, 2017.
  - Qiu, B., Oka, E., Bishop, S.P., Chen, S., and A.J. Fassbender. Decadal variability of the Kuroshio Extension system and its impact on subtropical mode water formation. Joint US CLIVAR Variations and OCB News edition entitled *Frontiers in western boundary current research,* November, 2017.
- Host/chair of US CLIVAR Variations Ocean Carbon Hot Spots webinar (November):
- PMEL Outstanding Paper Award nomination (December): Fassbender, A. J., C. L. Sabine, and M. F. Cronin. Net community production and calcification from seven years of NOAA Station Papa Mooring measurements. *Global Biogeochem. Cycles*, 30, 250–267, doi: 10.1002/2015GB005205, 2016.
- Elected early-career member of the Ocean Carbon and Biogeochemistry (OCB) Scientific Steering Committee from 2018 through 2020 (December).

- NSF proposal recommended for funding (January): “Constraining Upper-Ocean Carbon Export with Biogeochemical Profiling Floats,” ($683,207.00).

Recent Publications

- Feely, R.A., Okazaki, R.R., Cai, W.-J., Bednaršek, N., Alin, S.R., Byrne, R.H., A.J. Fassbender (2017). The Combined Effects of Acidification and Hypoxia on pH and Aragonite Saturation in the Coastal Waters of the California Current Ecosystem and the northern Gulf of Mexico. *Continental Shelf Research*, doi: 10.1016/j.csr.2017.11.002.

Steven Haddock (PI)
Biodiversity and biooptics

Recent Professional Activities

- Vice chair of the Marine Sanctuary's Research Advisory Panel.
- Research representative for the Sanctuary Advisory Council, which reports directly to the Sanctuary superintendent.
- Board member of the Deep-Sea Biology Society.
- Host of the upcoming 2018 Deep-Sea Biology symposium in Monterey.
- Steering committee member of the Global Invertebrates Genomics Alliance (GIGA).
- Adjunct faculty of UC Santa Cruz, Department of Ecology and Evolutionary Biology.
- Adjunct at Smithsonian National Museum of Natural History.
- Photograph of a deep-sea worm appears on a postage stamp issued for bioluminescence.
- Received the 2018 Ed Ricketts Memorial Award from the Monterey Bay National Marine Sanctuary.
- *BBC Blue Planet II* series aired, using footage we obtained with a special low-light camera, February 2018
- Food web video accompanies Choy *et al.* (2017) study of deep-sea food webs, January, 2017.
- Articles about our food-web research appeared in *New York Times*, etc. NYT article was selected for in top 10 reads of 2017, December 2017.
- NSF article on DEEPC was top 10 of year, December, 2017.
- Quartz video, *Unlocking the secret superpowers of jellyfish*, received over 500k views, November 2017.
- Audio interview and photographs used for *Ocean Trilogy* performance of Spector Dance, October 2017
- National Geographic *Hostile Planet* series aired, September 2017

Publications

- Choy, C.A., S.H.D. Haddock, B.H. Robison (2017). Deep pelagic food web structure as revealed by in situ feeding observations. *Proceedings of the Royal Society of London B. 284:* 20172116 dx.doi.org/10.1098/rspb.2017.2116.
- Hoving, H.J.T., S.L. Bush, S.H.D. Haddock, B.H. Robison (2017). Bathyal feasting: post-spawning squid as a source of carbon for deep-sea communities. *Proceedings of the Royal Society of London B.* 284: 20172096.

Brett Hobson

Long-range AUV (LRAUV) Artic Domain Awareness

This externally funded project is working in parallel with an internal project to build a new long-range AUV to demonstrate to the US Coast Guard how autonomous vehicles could be used under the Arctic ice to detect and track fuel or oil leaks. MBARI is building a new LRAUV with Woods Hole Oceanographic Institution (WHOI) for test deployments beginning in the summer of 2018. All of the parts have been delivered, and MBARI and WHOI technicians are building the sub-assemblies up in parallel with those required for the new MBARI vehicles.

LRAUV Payloads

The emphasis of the LRAUV engineering team has shifted from refining the vehicle to integrating new science payloads. Over the last quarter we have been focused on integrating 3G Environmental Sample Processors (ESPs) onto the MBARI and University of Hawaii (UH) vehicles. The three UH LRAUVs that were built under an NSF-funded collaboration between UH and MBARI will all be delivered to UH by March 10 and will be immediately sent to sea for a study on the microbial oceanography of open ocean eddies. Back at MBARI the team is also integrating a new bioluminescence instrument for Steve Haddock as well as supporting ongoing operations for the groups of Francisco Chavez, Chris Scholin, and Yanwu Zhang. LRAUV *Tethys*, MBARI's oldest LRAUV, is undergoing an update to the computer, motherboard, and wiring to bring her the same standards as the rest of the fleet and is expected to be running again by March.

Ken Johnson (PI) and Carole Sakamoto
More than 16-year time series of hourly in situ nitrate measurements on M1 captures interannual variability and provides insights into new production

From MBARI's inception, the development of chemical sensors has been a research focus. The In Situ Ultraviolet Spectrophometer (ISUS) is a low-power sensor developed at MBARI that is used to measure dissolved nitrate. Nitrate is an essential plant nutrient, exerting primary control on phytoplankton growth rates and biomass in aquatic environments so its measurement is critical to understanding biogeochemical cycling. The ISUS has been utilized in diverse environments ranging from the Southern Ocean to the Arctic and from the depths of the ocean basins to estuarine and freshwater environments . These sensors have been deployed on a diverse array of platforms such as ROVs, AUVs, benthic flux chambers, moorings, and profiling floats.

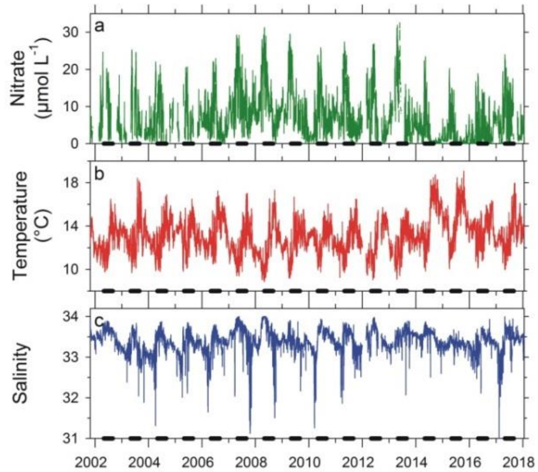


Figure 1. (a) hourly nitrate, (b) temperature, and (c) salinity from the M1 mooring. The tic marks are January 1 of the year axix label. Black bands mark the May-August time period.

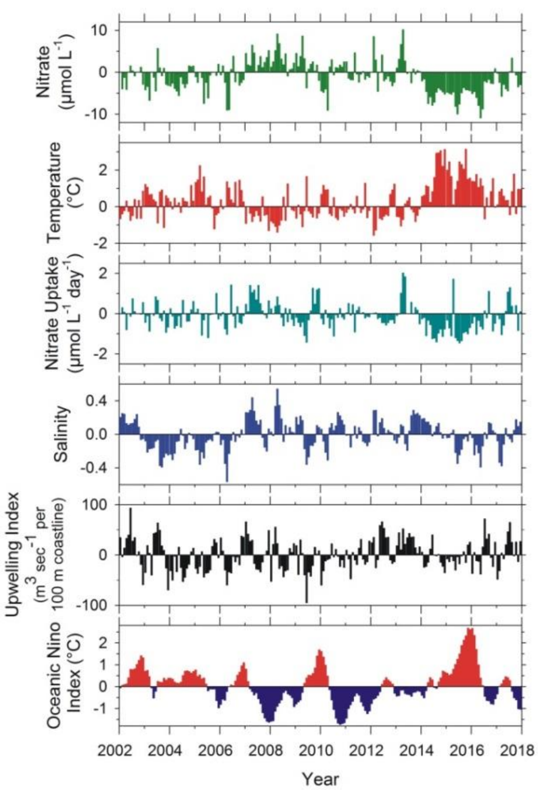


Figure 2. Top to bottom: M1 nitrate, temperature, nitrate uptake, salinity, and upwelling index monthly anomalies. The bottom panel is the Oceanic Nino Index (ONI) from www.pfeg.noaa.gov which is one measure of the El Nino-Southern Oscillation.

Deployments of an ISUS sensor on the MBARI M1 oceanographic mooring began in October 2001. The ISUS has remained an integral part of the M1 sensor suite for over 16 years since. In a paper accepted to the journal *Oceanography* for the 30-year MBARI retrospective, we analyzed the results from these ISUS deployments. This rich data set (Figure 1) captured seasonal and interannual variability from El Niño, La Niña, and water mass anomalies (the Warm Blob). To emphasize the interannual variability, the 2001-2013 data was binned into a monthly "average year" and subtracted from monthly binned data to plot monthly anomalies along with the Oceanic Nino Index (ONI- blue La Nina conditions, red, El Nino conditions) (Figure 2). In general, La Niña is associated with saltier, colder, higher nitrate, and higher nitrate uptake while El Niño is associated with fresher, warmer, lower nitrate and lower nitrate uptake. The most distinct anomaly period is 2014-2016 with very warm years. This anomalous warm water became referred to as "The Blob" in the press. This anomalous low-nutrient warm water was associated with the largest recorded outbreak of a coast-wide toxic algal bloom affecting closures of fisheries and propagating up the food chains to ultimately affect the health of marine mammals.

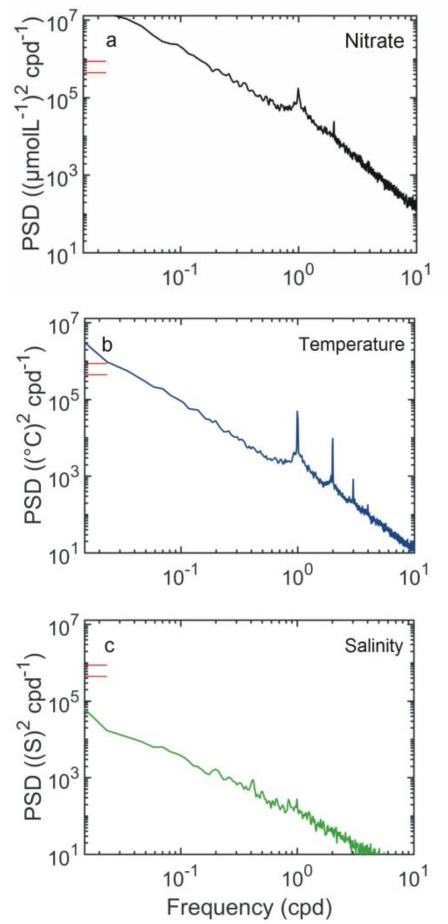


Figure 3. Power spectral density (PSD) estimates of (a) nitrate, (b) temperature, and (c) salinity data. The red solid lines represent the 95% confidence interval.

In addition to capturing interannual and seasonal variability, the high temporal resolution of the hourly data allowed quantification of diel cycles of nitrate uptake which can serve as a proxy to new production. To compute nitrate uptake by phytoplankton, the hourly measurements were analyzed for their frequency content. Power spectra density (PSD) plots were generated to identify periodicities in the data (Figure 3). Distinct peaks at exactly one cycle per day (cpd) are seen in the nitrate and temperature data (Figures 3a, b) but not in the salinity data (Figure 3c). The daily signal in temperature is due to the sun's insolation during the day and cooling during the night. The one cycle per day nitrate signal is due to nitrate being taken up by phytoplankton during growth in the daylight ("drawdown") overcoming resupply processes.

To further examine the diel nitrate signal, the data were passed through a 34-hour high-pass filter to remove low-frequency processes, such as upwelling events, while keeping the daily variability. The high pass filtered data were used to generate daily nitrate uptake values by finding the minimum value between 12-8 pm each day and subtracting it from the maximum value between the previous 12 am-12 pm for that day. This daily decrease in nitrate during the daytime is a result of the need for solar energy to power nitrate uptake in most phytoplankton.

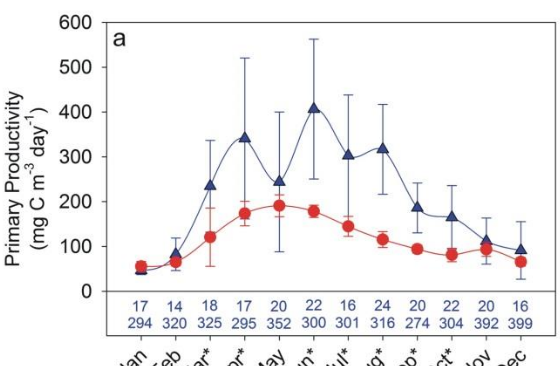


*Figure 4. Monthly mean daily nitrate uptake values (red circle) converted to C and ^{14}C primary productivity values (blue triangle) binned by month. The mean and 90% confidence intervals are plotted. The number of observations are listed at the bottom of the chart. *indicates months with significantly different medians.*

The daily nitrate uptake values (converted to C using the Redfield ratio) and the ^{14}C primary production data from cruises were binned by month and the monthly mean and 90% confidence interval are plotted in Figure 4. The medians for the winter months of November-February are statistically similar with low values for both nitrate uptake and ^{14}C primary production. May has the highest nitrate uptake but the ^{14}C primary production is only slightly higher and the median is not significantly different. The remaining upwelling months have statistically significantly higher medians of ^{14}C primary production than the nitrate uptake.

Recent publications

- Bittig, H. C., A. Körtzinger, C. Neill, E. van Ooijen, J. N. Plant, J. Hahn, K. S. Johnson, B. Yang, S. R. Emerson (2017). Oxygen optode sensors: principle, characterization, calibration and application in the ocean, *Frontiers in Marine Science*, doi: 10.3389/fmars.2017.00429.
- Briggs, E. M., T. R. Martz, L. D. Talley, M. R. Mazloff, and K. S. Johnson (2017). Physical and Biological Drivers of Biogeochemical Tracers Within the Seasonal Sea Ice Zone of the Southern Ocean From Profiling Floats, *Journal of Geophysical Research Oceans*, doi: 10.1002/2017JC012846.
- Bushinsky, S. M., A. R. Gray, K. S. Johnson, and J. L. Sarmiento (2017). Oxygen in the Southern Ocean from Argo floats: determination of processes driving air-sea fluxes, *Journal of Geophysical Research Oceans*, doi:10.1002/2017JC012923.
- Stanev, E. V., P.-M. Poulain, S. Grayek, K. S. Johnson, H. Claustre, and J. W. Murray (2018). Understanding the dynamics of the oxic-anoxic interface in the Black Sea, *Geophysical Research Letters*, 45. https://doi.org/10.1002/2017GL076206.

Meetings and Presentations

- Argo Data Management Meeting, Hamburg, Germany, November 27-December 1.

Kakani Katija (PI)
Deep-sea bioinspiration

Since summer 2017, we have been establishing the Bioinspiration Lab at MBARI, whose core team members develop tools, deploy instrumentation, and conduct laboratory studies of midwater and benthic organismal ecomechanics for bioinspired engineering design applications. These efforts involve engineering, science, and administrative tasks, which include the following:

Engineering activities:

- We are integrating a new laser on DeepPIV that will double the illumination power output from the current version (Figure 1A). We acquired two Coherent, 2 W, 639 nm DPSS lasers in fall 2017 and are testing both systems with planned integration for June 2018 deployments.
- We conducted a feasibility study for 3D flow measurements using plenoptic imaging hardware called EyeRIS. We are in the process of testing similar hardware on loan from NOAA, and working with partners at National Oceanography Centre and Henry Ruhl (CenCOOS) to fund the initial acquisition of hardware.

Scientific activities:

- The DeepPIV instrument has been deployed on nearly 80 ROV dives since summer 2015. These efforts have largely been conducted during midwater dives, with deployments during benthic dives planned with Senior Scientist Jim Barry in summer 2018.
- During our last midwater cruise with Senior Scientist Bruce Robison, we successfully conducted 3D reconstructions of relatively rare larvaceans' (*Mesochordaeus*) mucus house. This effort was especially challenging due to the fragile mucus structure, and could not have been accomplished without the masterful skills of MBARI's ROV pilots.
- We are working closely with the Video Lab to streamline the annotation and analysis of DeepPIV video data, and the subsequent integration of the data in VARS.

Administrative activities:

- Establishing the Laser Lab, a shared-use space that will enable safe operation of lasers at MBARI (Figure 1B).
- Assisting with LRAUV lab and cubicle renovations to enable more effective use of shared space over multiple engineering development projects (Figure 1C and D).
- Hiring (1) an NSF-funded Research Assistant as part of a collaboration with MBA and Hopkins Marine Station, to study jellyfish movement ecology by deploying animal-borne sensor packages; (2) searching for a Research Engineering Technician who will support all activities of the Bioinspiration Lab; and (3) NSF-funded Machine Learning Postdoctoral Researcher as part of a collaboration with Steve Rock (Stanford University) to enable robust, automated tracking algorithms of state-changing midwater targets on autonomous vehicles.
- Establishing the Deep Ocean Inspiration Group. External members of the working group come from diverse backgrounds (e.g., optical physics, materials science, computational physics, mathematics, experimental fluid mechanics, and organismal biologists), and whose

shared interests stem from bioinspired engineering design. Members will participate in the Bioinspiration Lab's planned research cruises in 2018.

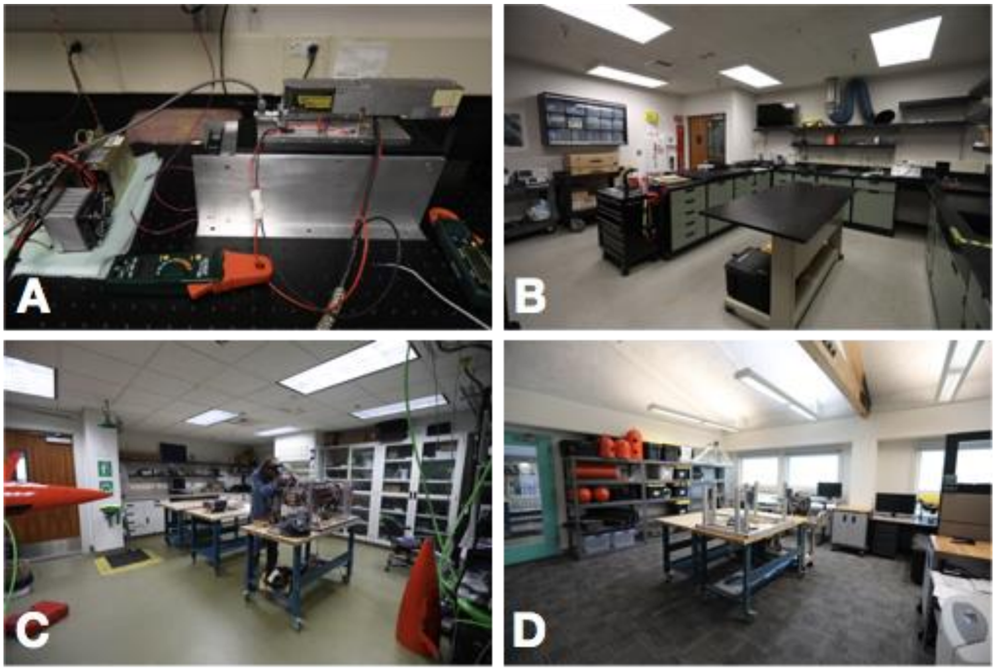


Figure 1. Activities include (A) testing and integration of a new laser, establishing the (B) Laser Lab, (C) reorganizing the LRAUV lab space and (D) cubicle area for more effective use of shared space.

Publications and Presentations (* - invited talk, <u>underline</u> – advised student)
First three are from ASLO Ocean Sciences Meeting, February 11-16, Portland, OR:

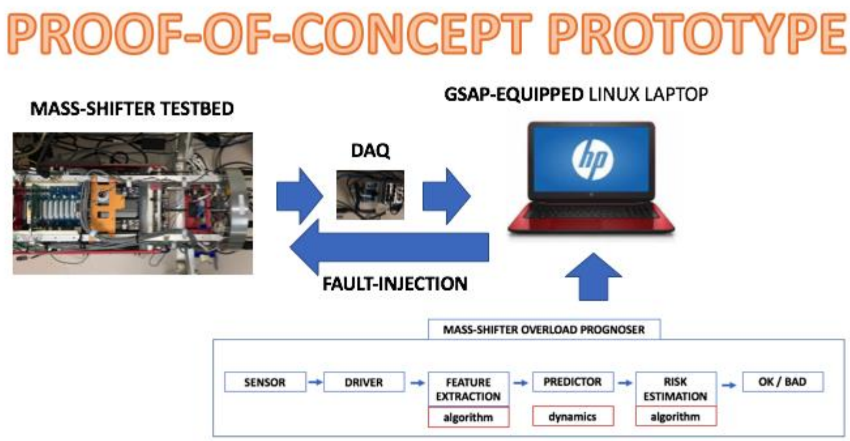
- Yoerger, D., Breier, J.A., Curran, M., Fujii, J., German, C.R., Gomez-Ibanez, D., Govindarajan, A., Hobson, B., Howland, J., Katija, K., Llopiz, J., Pontbriand, C., Risi, M, Robison, B.H., Rock, S., Wiebe, P.H. (2018). Mesobot: An autonomous underwater vehicle for tracking and sampling midwater targets.
- Mooney, T.A., <u>Flaspohler</u>, G.E., Caruso, F., Katija, K., Fontes, F., Afonso, P., Shorter, K.A. (2018). Fine-scale locomotion patterns of the veined squid, *Loligo forbesi*, measured using a novel bio-logging tag.
- Katija, K., Sherman, A.D., Sherlock, R.E., Robison, B.H. (2018). DeepPIV: Elucidating small-scale zooplankton-particle interactions in the deep sea.
- Katija, K., Sherlock, R.E., Sherman, A.D., Robison, B.H. (2018). DeepPIV reveals how mucus houses of deep sea, giant larvaceans are built. Society of Integrative and Comparative Biology Annual Meeting, January 3-7, San Francisco, CA.
- Katija, K.* (2017). DeepPIV: Measuring carbon fluxes in the mesopelagic using particle image velocimetry. Pump It Up Workshop, September 28-29, Woods Hole, MA.
- From outer to inner space: How exploration leads to inspiration. Stanford Women's Perspectives Seminar, Stanford University, January 25, 2018, Palo Alto, CA.

- DeepPIV: Measuring small-scale fluid motion in the deep sea. Stanford Fluid Mechanics Seminar Series, Stanford University, November 28, 2017. Palo Alto, CA.
- New technology enables the study of biomechanics, functional morphology, and ecology of giant larvaceans in the deep sea. Ocean Sciences Seminar Series, University of California, Santa Cruz, October 13, 2017, Santa Cruz, CA.
- New technology enables the study of biomechanics, functional morphology, and ecology of giant larvaceans in the deep sea. Joint Biology and Physics Seminar Series, Bates College, September 26, 2017. Lewiston, ME.

Mathieu Kemp (PI)

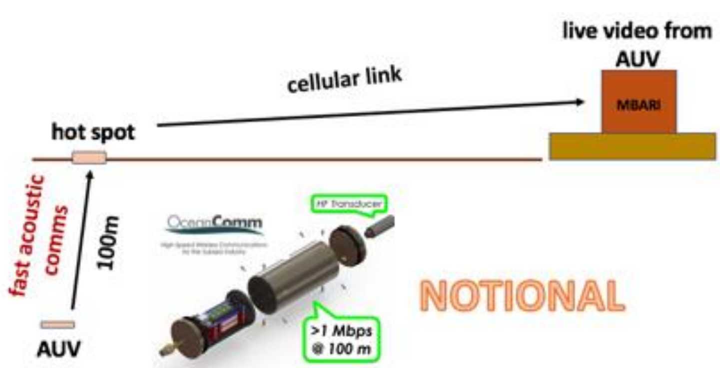
Fault Prognostication project highlights

The goal this year is to design and test an add-on device that can predict failures of the LRAUV before they occur. To achieve this goal, we will use agile design methods and start with a proof-of concept mass-shifter prognoser in spring 2018, followed by fabrication of a first article in summer 2018, and initial at-sea deployment in late fall 2018. This development will leverage the Generic Software Architecture Prognostics framework recently developed by NASA Ames.



WetWifi project highlights

The goal of this project is to perform a technical evaluation of an acoustic modem developed by OceanComm Inc. who recently achieved data rates of 1 Mbps in Lake Michigan; similar performance in ocean conditions could be transformational. Joint at-sea testing in Monterey Bay are planned for early February, late March, early May, mid-July, and mid-September. If the outcome of these tests is positive, the evaluation will be followed by a proof-of-concept phase in 2019, aimed at showing that near-real-time transfer of very large data files between a submerged AUV and a shore-based operator is possible.



Recent Publication

B. Raanan, M. Kemp, et al. Detection of unanticipated faults for AUVs using online topic models. *Journal of Field Robotics*.

Professional Activities

- Presentation at Navy Research Laboratory, “Failure forecasting for AUVs.”
- Meeting with NASA Ames' Prognostics Center of Excellence to discuss integration of their prognostication software framework to an AUV.
- Awarded adjunct professorship at Duke University ECE department.
- PhD dissertation committee for Andrew Young in Duke University’s ECE department.

Brian Kieft and Tom O'Reilly
Hot Spot Support

Brian Kieft with Wave Glider and LRAUV Opah*.*

We successfully exported the Hot Spot to University of Hawaii with successful field testing in December, proving autonomous tracking of LRAUV *Opah* off Diamond Head (above). Quarterly visits to Station M continued on schedule and good Benthic Rover health was confirmed. Additionally, Hot Spot geo-located the Benthic Rover at 4,000 meters depth following redeployment in November, using acoustic range-only algorithm developed by our collaborator Ivan Masmitja (SARTI-UPC). We completed conversion of Hot Spot payload to 1U payload box for the SV3. This configuration has been integrated with University of Hawaii's Wave Glider and will be used to acoustically track the submerged MiVEGAS LRAUVs and quickly retrieve their data when they surface.

Charlie Paull (PI)
Continental margins project

The continental margins project had a big showing at the December American Geophysical Union meeting in New Orleans. There was an entire oral section devoted to results of the Coordinated Canyon Experiment (CCE). In total, there were 18 presentations about the CCE and another six presentations covering AUV mapping studies off Taiwan and in the Arctic.

18 members of the CCE team, during CCE data interpretation workshop which was held at MBARI in July. All but two made AGU presentations.

Recent Professional Activities

- "Tracking the movement of sediment through Monterey Canyon," UC Berkeley seminar, October 4, 2017.
- "Direct measurement of the impact of sediment gravity flows on seafloor morphology," lead lecture, November 11, 2017, at 9th International Conference on Geomorphology, New Delhi, India.
- Hosted workshop, "California Seafloor Exploration Planning," to coordinate research and exploration off Central California in part driven by the potential development of offshore wind farms.

Publications

- Carvajal, C., Paull, C.K., Caress, D.W., Fildani, A., Lundsten, E., Anderson, K., Maier, K.L., McGann, M., Gwiazda, W., Dykstra, M., and Herguera, J.C. (2017). Unraveling the channel-to-lobe-transition zone with high-resolution AUV bathymetry: Navy Fan, offshore Baja California, *Journal of Sedimentary Research,* v. 87, p. 1049-1059, doi.org/10.2110/jsr.2017.58.
- Covault, J.A., Kostic, S., Paull, C.K., Sylvester, Z., and Fildani, A., 2017, Cyclic steps and related supercritical bedforms: Building blocks of submarine fans and canyon-channel

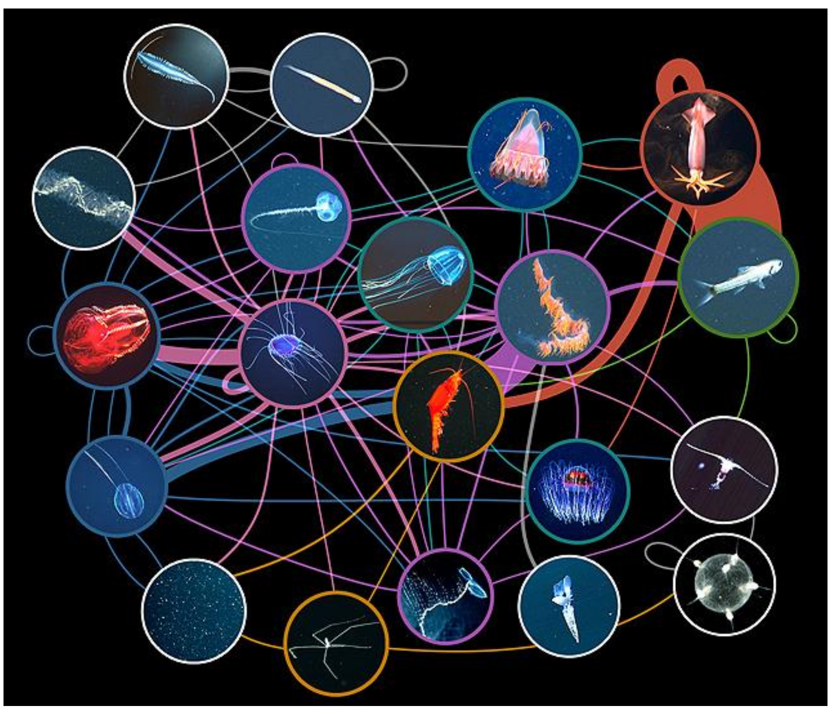
systems, Western North America, *Marine Geology*, v. 393, p. 4-20, doi.org/10.1016/j.margeo.2016.12.009

- Amblas, D., Ceramicola, S., Gerber, T.P., Canals, M., Chiocci, F.L., Huvenne, V.A.I., Lai, S.Y.J., Lastras, G., Lo Iacono, C., Micallef, A., Mountjoy, J.J., Paull, C.K., Puig, P., and Sanchez-Vidal, A., 2017, Submarine canyons and gullies, in: *Submarine Geomorphology*, Micallef, A., Krastel, S., and Savini, A., (eds.), Springer Nature, p. 251-273.

Bruce Robison (PI)
Food webs and trophic pathways

We are working with Postdoctoral Fellow Anela Choy on using biochemical markers to identify and quantify trophic pathways in the pelagic food web. This approach is based on the analysis of carbon and nitrogen stable isotope compositions. A preliminary step in developing this biochemical food web is a recently published paper (Choy et al., 2017) on the midwater food web of Monterey Bay, based on 25 years of ROV video observations of feeding interactions. This is the first such publication of its kind.

Complementing the overall food web research have been publications on individual feeding patterns among several midwater species. These include larvaceans (Katija et al., 2017), gonatid squids (Hoving and Robison, 2016), vampire squids (Hoving and Robison, 2012), medusae (Skikne et al., 2009), ctenophores (Swift et al., 2009), fishes (Drazen et al., 2007), and more. Because our mesopelagic animals are an important food source for many commercially harvested pelagic species, this information has significant implications for ocean health as well as for human health. We are also investigating the distribution of plastic pollutants through the midwater food web, in a partnership with the MBA.



The figure above is an in situ food web of the greater Monterey Bay deep-pelagic ecosystem, as represented by 20 broad taxonomic groupings as derived from ROV-based observations of feeding. The flow of energy from predator to prey is color coded according to predator group origin, and loops indicate within-group feeding. The thickness of the lines or edges connecting food web components is scaled to the number of unique ROV feeding observations across the years 1991-2016 between the two groups of animals. The different groups have eight color-coded types according by main animal types as indicated by the legend and defined here: red=cephalopods, orange=crustaceans, light green=fish, dark green=medusa, purple=siphonophores, blue=ctenophores, and gray=all other animals.

Invited Seminars & Presentations

- National Academy of Sciences, Science & Entertainment Exchange, Hollywood Salon.
- “Exploring the oceanic water column: it’s a matter of perspective”, session keynote at ASLO Ocean Sciences Meeting.
- NOAA/OER Water Column Workshop on midwater research at MBARI.
- Seminar series, Evolution Matters, at Harvard University.
- “Advances in Midwater Biology: progress from in situ research,” ecology seminar at Scripps Institution of Oceanography.
- National Steinbeck Forum on migrations in the deep ocean.
- “Deep-Sea Discoveries in Monterey Bay: Improbable Animals & Unexpected Stories,” 25th anniversary lecture series for Monterey Bay National Marine Sanctuary;

Publications

- Choy, C.A., Haddock, S.H.D., Robison, B.H. (2017). Deep pelagic food web structure as revealed by in situ feeding observations. *Proceedings of the Royal Society B*. 284: 20172116, doi: 10.1098/rspb.2017.2116.
- Robison, B.H., K.R. Reisenbichler, R.E. Sherlock (2017). The Coevolution of Midwater Research and ROV Technology at MBARI. *Oceanography: special issue.*

Ken Smith (PI)
Pelagic-Benthic Coupling

There is growing evidence that large quantities of particulate organic carbon (POC) produced in surface waters reach abyssal depths within days during episodic flux events. A 28-year record of in situ observations was used to examine episodic peaks in POC fluxes, detrital aggregate cover, and sediment community oxygen consumption (SCOC) at Station M (NE Pacific, 4,000 m depth; Figure 1). An increasing proportion of annual POC flux to abyssal depths occurred during episodic, high-magnitude POC flux events (i.e. ≥ 1.5 σ; Figure 2A). From 2011 to 2016, time lags between changes in satellite estimated export flux (EF), POC flux to the seafloor, and ultimately SCOC varied between each flux event from 0 to 70 days suggesting variable remineralization rates and/or particle sinking speeds (Figure 2B). Peaks in EF overlying Station M frequently translated to changes in POC flux to the abyss. A Martin curve model was used to estimate abyssal fluxes from EF and midwater temperature variation. The episodic events were significantly underestimated by the model, which leads to an underestimate of the overall flux by almost 50% (Figure 2C). Episodic pulses of organic carbon into the deep sea are critical in balancing the oceanic carbon budget. (This work was submitted to *Limnology and Oceanography* for review in December 2017).

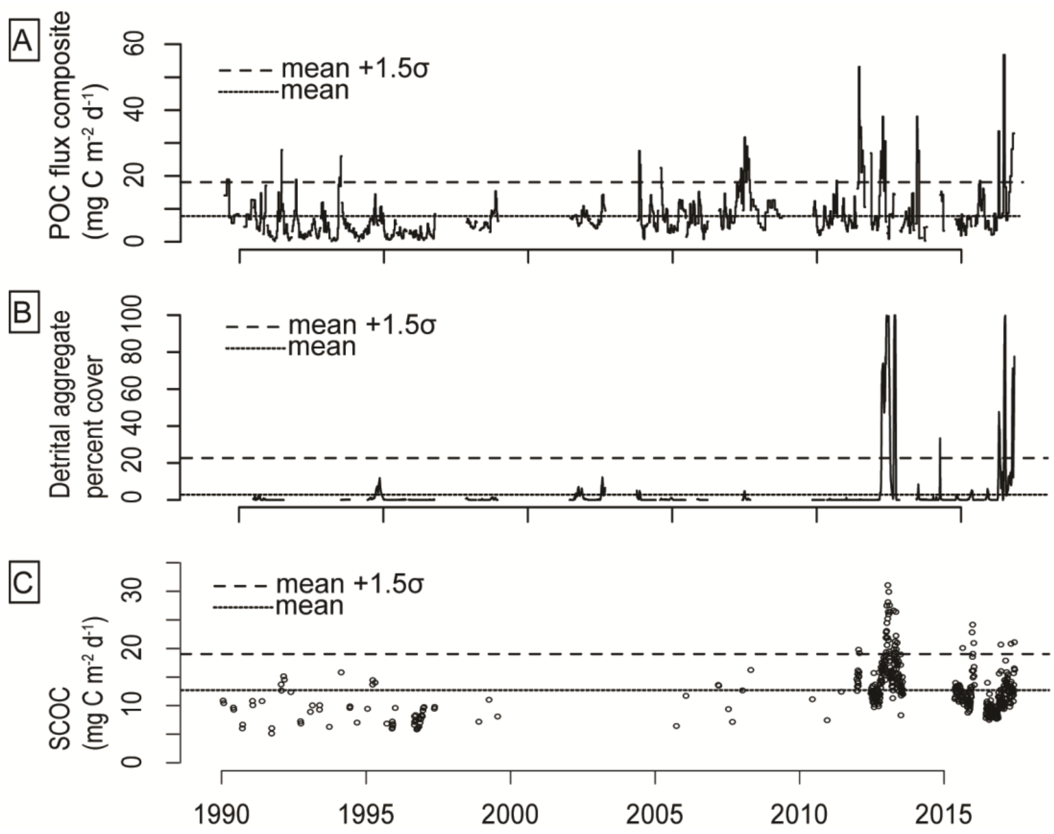


Figure 1. Full Station M time series of A) trap-measured particulate organic carbon (POC) flux (dotted line at mean of 7.8 mg C m^{-2} d^{-1}, dashed line at mean + 1.5 σ = 18.0 mg C m^{-2} d^{-1}), B) detrital aggregate (DA) % cover on the seafloor (dotted line at mean of 3.0 %, dashed line at mean + 1.5 σ = 22.8 %), and C) sediment community oxygen consumption (SCOC; dotted line at mean of 12.7 mg C m^{-2} d^{-1}, dashed line at mean + 1.5 σ = 19.0 mg C m^{-2} d^{-1}).

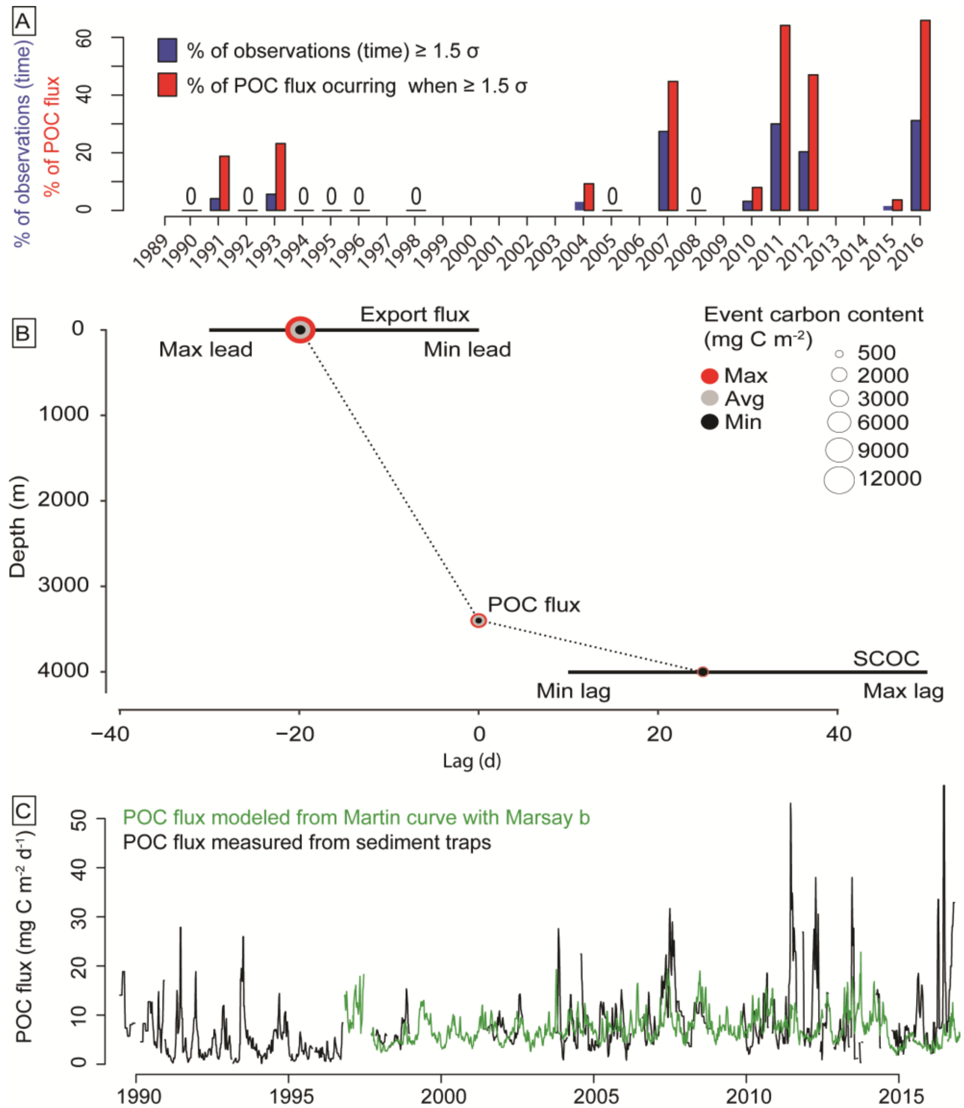


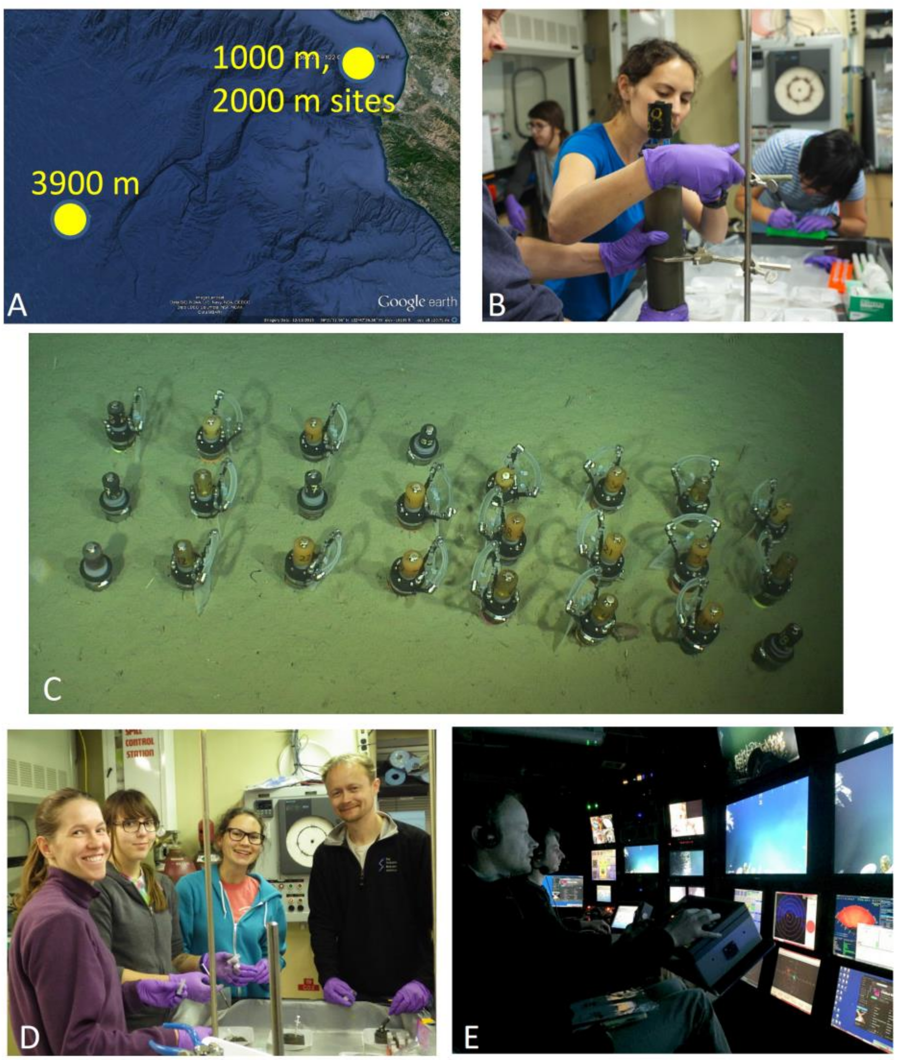
Figure 2. Variation in flux patterns to abyssal depths at Station M. top) Fraction of the yearly sampling and particulate organic carbon (POC) flux during periods with values ≥ 1.5 σ above the long-term average, for years with ≥ 75% sampling coverage. middle) Average, minimum, and maximum carbon content, and time lags from export flux (EF), particulate organic carbon (POC) flux pulse events, and sediment community oxygen consumption (SCOC). bottom) Particulate organic carbon (POC) flux measures and estimates for Station M from 1989-2016 (black = POC flux measured from sediment traps; blue = POC flux estimated from Martin et al. (1987) using the temperature-dependent b-term from Marsay et al. (2015). The b term was set using the equation b = 0.062(T) + 0.303, where T was obtained from a time-series of temperature at 250 m near Station M that covers the study period (Marsay et al. 2015). The temperature time series was constructed as a combination of the California Current System 13-Year and 31-Year Historical Reanalyses (Neveu et al., 2016) with outputs from the Near Real Time assimilative model provided by University of California, Santa Cruz (http://oceanmodeling.ucsc.edu).

Professional Activities

- Mentoring CSUMB graduate student Larissa Lemon
- Mentoring CSUMB graduate student Danielle Fabian
- Sailed as Chief Scientist on research cruise to Station M, R/V *Western Flyer*, November 8-16, 2017.

Alexandra Z. Worden (PI)
Identifying which microbes actively degrade phytoplankton detritus in the deep sea

Many studies characterize microbial diversity, but most of them cannot discriminate between which microbes are the most active and important for organic matter degradation versus those that might just be very slow growing and less important to the carbon cycle. We designed two systems that are deployed using the remotely operated vehicle that enable us to discover which community members are active, and follow their activities over time. One system is used in the sediments and the other with deep sea water that overlies the sediments. Our big deployment at 3,900 meters was scheduled for September 2017, but due to the *Western Flyer's* emergency trip to the shipyard, it was postponed and has just been performed successfully. In fact it was the largest deployment of push cores in MBARI history! This project involves a collaboration with Victoria Orphan (Cal Tech, and also an MBARI adjunct) who is performing chemical analyses on the sediment samples.



(A) Microbial communities are being investigated at different sites, including some where a whale decayed and others that did not received this kind of perturbation. (B) Worden Lab graduate student Rachel Harbeitner Clark samples from a sediment core. (C) An array of injector (incubator cores) and standard push cores at 3,900 m. (D) Worden Lab technician Cami Poirier, graduate students Maria Hamilton and Rachel Harbeitner Clark, and Research Specialist (Chief Scientist) Sebastian Sudek in the lab of the Western Flyer*.* *(E) Sebastian Sudek in the ROV control room.*

Recent Professional Activities

- Editorial Board, *Protist*
- ENIGMA Scientific Advisory Committee
- Full Professor Adjunct, UC Santa Cruz, Ocean Sciences
- Organizing Committee for International Society of Photosynthesis Research Meeting
- PhD Advisor for Juliana Nzongo, Maria Hamilton, Rachel Harbeitner, and Charlotte Eckmann
- Panel Member for the European Research Council
- Invited Speaker, EMBO Conference on comparative genomics of eukaryotic microbes: dissecting sources of evolutionary diversity, Sant Feliu de Guixols, Spain.
- Invited Seminar Speaker, Max Planck Institute for Developmental Biology, Tübingen, Germany.

Yanwu Zhang
Targeted Sampling by Autonomous Vehicles

Yanwu is working with LRAUV teammates and collaborating with the ESP team. He developed algorithms and mission scripts for the 3G Environmental Sample Processor 60-cartridge field tests in December and January. He is working with Carlos Rueda, Chris Wahl, and LRAUV team, and he used Wave Glider *Tiny* to autonomously track an upwelling front in Monterey Bay over 39 hours in October.