

EXECUTIVE SUMMARY

YEAR TWO ANNUAL REPORT

OCEAN EXPLORATION COOPERATIVE INSTITUTE



EXPLORING THE NATION'S BLUE FRONTIER





Background

The Ocean Exploration Cooperative Institute (OECI) is an integrated ocean exploration enterprise that leverages the unique and world-class knowledge and expertise of its partner institutions and NOAA. The OECI aims to advance ocean exploration through the conception and development of new vehicles, sensors and operational concepts; the execution of field-based ocean exploration utilizing these new technologies; enhancing the approaches and infrastructure to the collection, analysis and delivery of ocean exploration data; and by inspiring and training a new and more diverse generation of ocean explorers. The following summarizes OECI Year Two activities in supplement to the complete annual report submitted to the National Oceanic and Atmospheric Association (NOAA).

In the second year of existence, the OECI has solidified leadership, both within itself and at NOAA. Adam Soule has been appointed as executive director of the OECI. Soule replaces Interim director Dwight Coleman, who resumes his role as director of the Inner Space Center at the University of Rhode Island (URI). Soule has spent the previous 17 years as a staff scientist at the Woods Hole Oceanographic Institution (WHOI) conducting deep sea research on submarine volcanic systems. Over the last seven years, Soule served as the chief scientist for deep submergence at WHOI, providing scientific leadership for the National Deep Submergence Facility (NDSF) and for the community of ocean scientists who use the NDSF. In addition, Jason Fahy has joined the OECI staff as project manager. Jason comes from a 20 year career in the U.S. Navy, working with autonomous underwater vehicles. Fahy brings tremendous field and management experience to the OECI executive office.

At the University of Southern Mississippi (USM), Dr. Kelly Lucas has taken over as principal investigator from Monty Graham. Lucas has expertise managing a large research enterprise as vice president of marine operations at USM. Dr. Leo Maccelloni has replaced Brian Connon as USM's representative to the OECI's council of fellows. Maccelloni has a background in geophysics and manages USM's fleet of autonomous vehicles.

At NOAA, Dr. Alan Leonardi has departed as director of the Office of Ocean Exploration (NOAA OE). Leonardi was central to the development of the OECI, providing guidance on everything from the structure of OECI management to the scientific directions that best aligned with NOAA's objectives. His leadership will be missed, but he is replaced by the highly capable Dr. Genene Fisher and the excellent leadership team he has developed at NOAA OE. In addition, Dr. Aurora Elmore has been appointed as project manager for the OECI. Elmore transitioned from a position at National Geographic where she managed expeditions and project development including an expedition to Mt. Everest. Dr. Elmore has brought tremendous energy and communication skills to the role.

Since its inception in July 2019, significant spin-up has been required to get the OECI up and running. In Year Two OECI was disrupted



Far left: The control van on board E/V *Nautilus* supports vehicle dives from the surface. Left: Three AUVs are stowed after deployment and operation from the R/V *Point Sur*.

by the COVID-19 pandemic, which significantly limited at-sea operations as well as laboratory work within the OECI and across the academic community. As a result, many planned activities were delayed, including technology demonstrations, internship programs and exploration cruises. These startup and COVID-related delays, along with some technical and logistical challenges, have resulted in a significant excess of funds remaining from Year Two (and some from Year One). As we emerge from the global pandemic, the OECI is excited to have the resources at hand to execute the delayed projects alongside new Year Three projects to realize the vision of the OECI. In doing so, we are committed to catching up on spending by the end of Year Three.

Despite COVID-19, there was tremendous progress made in some key areas. Highlights from Year Two include the delivery of the DriX ASV to the University of New Hampshire (UNH), and overhaul of USM AUVs Eagle Ray and Mola Mola. In addition, there were successful demonstrations of the next-generation, lightweight and low-cost Orpheus AUV on *Okeanos Explorer*, and in Bermuda, a new class of midwater AUV, Mesobot. Several E/V *Nautilus* cruises occurred, during which nearly 50,000 square kilometers of the U.S. EEZ were mapped and 17 ROV dives for sampling and characterization of the seabed were conducted. In spite of COVID-19 personnel restrictions, these cruises were highly successful due to telepresence, which enabled scientific expertise to participate entirely from shore for some cruises.

Many Year-Two activities that were postponed will occur in the coming months, fulfilling the Year-Two objective of operationalizing new and improved tools that make up the stable of OECI vehicle systems. This positions the OECI for a key Year-Three activity: to increase ocean exploration capacity by developing operational concepts for multi-vehicle, cooperative exploration, as well as telepresence that will move scientific, engineering, and operational tasks to shore.

The OECI submitted an augmentation to its original proposal. The resulting award raised the cap on funding to a total of \$150 million over five years (2021–2024). The augmentation proposal included a number of exciting potential projects of interest to NOAA OE and other NOAA line offices. Those projects include:

- Development of new vehicles, including a 6000-meter-rated AUV
- Focusing on capabilities of new vehicles, such as collaborative networks for ASVs
- Sensor development, including those designed for in situ analyses of rock chemistry for characterizing critical minerals, and
- Harnessing machine learning and cloud computing to more efficiently process ocean exploration data.

Projects were also developed in collaboration with NOAA Fisheries and National Marine Sanctuaries that would bring the considerable expertise of the OECI to scientific objectives of these NOAA offices.

Glossary

Commonly Used Acronyms

- 4K** 4000-pixel video resolution (horizontal)
- AUV** Autonomous Underwater Vehicle
- ASV** Autonomous Surface Vehicle
- EEZ** Exclusive Economic Zone
- ROV** Remotely Operated Vehicle

Organizations and Institutions

- CCOM** Center for Coastal and Ocean Mapping at UNH
- NOAA** National Oceanic and Atmospheric Administration
- OECI** Ocean Exploration Cooperative Institute
- OET** Ocean Exploration Trust
- UNH** University of New Hampshire
- URI** University of Rhode Island
- USM** University of Southern Mississippi
- WHOI** Woods Hole Oceanographic Institution

Vehicles and Vessels

- C-Worker 4** ASV owned by CCOM at UNH
- DriX** ASV manufactured by iXBlue
- Eagle Ray** AUV manufactured by International Submarine Engineering
- Mola Mola** AUV developed by WHOI and owned by USM
- Nautilus** Exploration vessel owned and operated by OET
- Okeanos Explorer** Exploration vessel owned by NOAA
- Orpheus** AUV developed by WHOI

2020–2021 Highlights

- Five robotic vehicles—one ROV, three AUVs, and one ASV— were deployed for more than 400 hours.
- 48,000 square kilometers of seafloor was mapped.
- 375 hours of HD and 4K subsea video was collected.
- One graduate student was fully supported.
- 13 undergraduate and graduate students were partially supported.
- OECI counted more than 2 million views of its videos and 170 thousand interactions with the public.

On the cover

Aboard *Okeanos Explorer*, Woods Hole Oceanographic Institution tested the AUV Orpheus. Photo by Jessica Kaelblein.

Technology Development

Year Two of the OECI saw further development of several ocean exploration tools. Construction of the DriX ASV was completed by IXBlue. It will be commissioned and delivered in the coming months. The DriX is an eight meter, wave-piercing ASV that has been shown to be incredibly seaworthy and capable of collecting excellent mapping data. The DriX is a critical piece of hardware for the OECI as it will serve the dual purpose of expanding mapping capacity by enabling concurrent multibeam sonar data collection by two vessels (e.g., DriX and *Nautilus*). The DriX will also serve as a force multiplier in AUV operations by acting as a communications gateway for over-the-horizon operations and cuing AUV behavior based on its data collection. After delays in delivery due to COVID-19, the OECI eagerly anticipates conducting sea trials and operationalizing this asset in the coming months.

Updates and upgrades to USM's AUVs Eagle Ray and Mola Mola occurred in Year Two. Eagle Ray received a complete refresh of its navigation and sensor package, which included a new inertial navigation system, doppler velocimetry logger, and multibeam sonar with water-column recording capabilities. The refreshed vehicle was tested at the end of Year Two and demonstrated its new capabilities. Mola Mola's refreshed imaging package was delayed due to COVID-19. This upgrade is expected to be completed in the coming months.

Orpheus, a new class of lightweight and low-cost AUV, is following a development path toward full-ocean-depth operation. It was tested onboard *Okeanos Explorer* in May, 2021. Orpheus and a second vehicle, Eurydice (a carbon copy of Orpheus), were deployed to depths of 866 meters, where they surveyed 30 kilometers of trackline and collected 724 gigabytes of 4K video. For positioning, Orpheus uses novel terrain-relative-navigation that was transitioned to the vehicle by engineers from NASA JPL following successful deployment on the Mars Perseverance Rover and companion drone.

Top: The Data Visualization Wall is a facility in the Center for Coastal and Ocean Mapping at the University of New Hampshire. Left middle: The DriX ASV (in red) is deployed for testing. Left bottom: The AUV Eagle Ray is prepped for deployment from the fantail of R/V *Point Sur*. Right: E/V *Nautilus* with the ROV Hercules in tow.

Exploration

NA122: "Seafloor mapping of the Cascadia Margin Deformation Front"

Between October 2 and 7 of 2020, seafloor mapping of the Cascadia Margin deformation front occurred from Astoria, Oregon to northern California. Priority areas from the Expanding Pacific Research and Exploration of Submerged Systems (EXPRESS) campaign were provided by the U.S. Geological Survey (USGS) to Ocean Exploration Trust (OET). To view the outreach materials created during this expedition as well as the participating team, visit the NA122 expedition page on NautilusLive.org.

NA124: "Biodiversity Baselines and Biopharmaceutical Potential for the Borderland"

A team of ecologists, microbiologists, zoologists and a geologist explored the Southern California Borderland (SCB) from October 27 to November 6, 2020. Goals for this cruise were to collect samples and data needed to generate baseline information describing faunal and microbial community structure and biopharmaceutical potential across two poorly explored, mineral-rich ecosystems that are associated with phosphorites and ferromanganese crusts in the SCB. To view the outreach materials created during this expedition as well as the participating team, visit the NA124 expedition page on NautilusLive.org.



NA125: "Seabed Mapping to Support the U.S. National Ocean Exploration and Characterization in the U.S. West Coast EEZ"

The final expedition of *Nautilus* in 2020 was a mapping-only cruise that targeted gaps in NOAA's U.S. bathymetry coverage and gap analysis within the U.S. EEZ. The primary mapping area was along the western boundary of the EEZ, west of San Diego. To view the outreach materials created during this expedition as well as the participating team, visit the NA125 expedition page on NautilusLive.org.

PS21-01: "AUV and ASV testing in the Gulf of Mexico"

USM's AUV operations team tested the Eagle Ray, Mola Mola, and C-Worker 4 with a new launch and recovery system at Mountain Top Bank. The Eagle Ray and Mola Mola were successfully launched and recovered. The Mola Mola collected a 60 by 60 meter photomosaic of the bank's summit. The C-Worker 4 collected a partial bathymetric and seafloor backscatter survey of Mountain Top Bank.



Education and Engagement

The OECI education efforts have progressed despite challenges posed by COVID.

- The Tuskegee University Ocean Club, established as part of the USM-led Tuskegee Partnership program, has met regularly online and hosted presentations by OECI partners, including OET and URI. We look forward to additional presentations with a focus on ocean engineering in Year Three.
- The internship program has been initiated and the first two Tuskegee University interns participated in a research cruise on the R/V *Point Sur* and conducted research at USM in June 2021.
- The OECI supported the graduate research of first-year Ph.D. student Coralie Rodriguez (above, left) with additional support from URI matching funds. Coralie’s research is focused on detailed geochemical analyses of ferromanganese crusts, collected by OET (above, inset), and the important elements these crusts hold. Coralie’s first results are coming in and she is excited to participate in a research cruise in December, 2021 to collect additional samples.

Above: Coralie Rodriguez, left, and professor Katherine Kelley, confer at the Marine Geological Samples Laboratory on URI’s Narragansett Bay Campus.

The OECI engagement program took important steps toward its Year Two goals.

- A logo was developed to assist with branding. It includes elements that speak to the global need for Ocean Exploration across the entire water column and the OECI’s mission to develop technology and autonomy to increase the pace and efficiency of exploration.
- The OECI’s website (oeci.org) was developed and launched to describe the mission of the OECI, the partners and partnership, the extant and developing ocean technologies, and pathways for involvement in OECI activities for scientists, students and the public. The OECI intends for this website to become a clearinghouse for links to OECI data and to tell amazing stories of OECI science and engineering successes and of the people that make them possible.
- The OECI shared its work with the broader public through targeted professional development programs for teachers produced in collaboration with NOAA OE’s education office. URI’s Inner Space Center brought a new level of professional production to these events that has made them both more engaging and effective.



Media Coverage

Above: A routine aspect of every mission, ship’s personnel assist with deployment and recovery of robotic vehicles. Below: Ocean Exploration Trust’s Megan Cook aboard E/V *Nautilus* speaks with a high school class visiting the University of Rhode Island’s Inner Space Center.

OECI activities have been extensively covered in the popular press. A list of coverage is included as part of the OECI Year Two metrics.

Notably, media attention to OECI has come in a variety of forms. The recent technology demonstration of the Orpheus vehicle on the *Okeanos Explorer* was covered by *WIRED* magazine, *Forbes*, and *Space.com*. An OECI-sponsored engineer participated in a Twitch live stream, which was viewed by thousands of members of the public, as it coincided with the release of a video game, *SubNautica*.



Partner News and Notes

OECI Council of Fellows Chair, **Allison Fundis**, was selected as a National Geographic Emerging Explorer. This honor was awarded to “15 individuals conducting innovative work focused on a range of topics such as inventing space technologies, ocean exploration, understanding the past through archaeology and anthropology, species conservation, storytelling, and elevating young voices for the future of education.”

Adding to his many accolades, OECI executive committee member and co-principal investigator **Dr. Larry Mayer** of UNH was elected as a foreign member of the Royal Swedish Academy of Sciences.

OECI executive committee member and co-principal investigator **Dr. Robert Ballard** of URI published his memoir, *Into the Deep*, which is the number one new release in “Nature > Oceans” on Amazon.com. The publication has garnered significant media attention.

OET partnered with Global Multi-Resolution Topography (GMRT) to pilot a workflow to speed integration of new mapping data into global compilations. **GMRT tiling tools** were adapted to use onboard during expeditions and were integrated into standard operating procedures. The workflow of submitting mapping data was improved and a testbed for tools that can benefit the broader seabed mapping community was provided. The goal is to ensure consistent quality of processed multibeam data, and to accelerate the production of high-quality integrated data products. Results were reported at the 2020 American Geophysical Union fall conference by Ferrini, et al.

Peer-Reviewed Publications

OECE-affiliated researchers have published dozens of articles related to OECE activities in Year Two. A partial list is provided below, additional publications will be listed on the OECE website.

Ware, C., **Mayer, L.**, Johnson, P., Jakobsson, M. and **Ferrini, V.**, 2020, A geographic grid system for visualizing bathymetry, *Geosci. Instrum. Method. Data Syst.*, 9, 375–384, <https://doi.org/10.5194/gi-9-375-2020>

Barker, L.D.L.; **Jakuba, M.V.**; **Bowen, A.D.**; **German, C.R.**; Maksym, T.; **Mayer, L.**; Boetius, A.; Dutriex, P.; Whitcomb, L.L. Scientific Challenges and Present Capabilities in Underwater Robotic Vehicle Design and Navigation for Oceanographic Exploration Under-Ice. *Remote Sens.* 2020, 12, 2588. <https://www.mdpi.com/2072-4292/12/16/2588/pdf>

Varghese, H.K., **Miksis-Olds, J.**, DiMarzio, N., Lowell, K., Linder, E., **Mayer, L.A.**, and Moretti, D., 2020, The effect of two 12-kHz multibeam mapping surveys on the foraging behavior of Cuvier's beaked whales off Southern California, *Jour. Acoustical Society of America*, v. 14, no. 6., pp. 3849-3858. <https://doi.org/10.1121/10.0001385>

Masetti, G., Smith, M. J., **Mayer, L. A.**, and Kelley, J. G. W., 2020, Applications of the Gulf of Maine Operational Forecast System to Enhance Spatio-Temporal Oceanographic Awareness for Ocean Mapping. *Frontiers in Marine Science*, v. 6., Sci., 14 January 2020 | <https://doi.org/10.3389/fmars.2019.00804>

Sowers, D., Masetti, G., **Mayer, L.A.**, **Johnson, P.**, **Gardner, J.V.**, and **Armstrong, A.**, 2020, Standardized Geomorphic Classification of Seafloor Within the United States Atlantic Canyons and Continental Margin, *Frontiers in Marine Science*, v. 7, pp. 9, <https://doi.org/10.3389/fmars.2020.00009>

Sowers, D., Dijkstra, J. A., Mello, K., Masetti, G., Malik, M., and **Mayer, L. A.**, 2020. Chapter 56 Application of the coastal and marine ecological classification standard to Gosnold Seamount, North Atlantic Ocean. In *Seafloor Geomorphology as Benthic Habitat* (pp. 903-916). doi:10.1016/b978-0-12-814960-7.00056-7

Yoerger, D., **Curran, M.**, **Fujii, J.**, **Gomez-Ibanez, D.**, **Govindarajan, A.**, **Howland, J.**, ... and **Wilkinson, C. J.** (2020, February). At-sea testing of the Mesobot midwater robot. In *Ocean Sciences Meeting 2020*. AGU.

Wilkinson, C. J., **Yoerger, D.**, **Adams, A.**, and **Wiebe, P. H.** (2020, February). Methods for investigating the effect of ambient light levels on diel vertical migration of midwater animals with the Mesobot AUV. In *Ocean Sciences Meeting 2020*. AGU.

Bünz, S., Ramirez-Llodra, E., German, C., Ferre, B., Sert, F., Kalenickenko, D., Reeves, E., Hand, K., Dahle, H., Kutti, T., Purser, A., Hilario, A., Ramalho, S., Rapp, H. T., Ribeiro, P., Victorero, L., Hoge, U., Panieri, G., **Bowen, A.**, **Jakuba, M.**, **Suman, S.**, **Gomez-Ibanez, D.**, **Judge, C.**, **Curran, M.**, **Nalicki, V.**, **Vagenes, S.**, **Lamar, L.**, **Klesh, A.**, **Dessandier, P. A.**, **Steen, I.**, **Mall, A.**, **Vulcano, F.**, **Meckel, E. M.** and **Drake, N.** (2020) R/V *Kronprins Håkon* (cruise no. 2019708) Longyearbyen – Longyearbyen 19.09. – 16.10.2019.

Bowen, A., **Jakuba, M.**, and **German, C. R.** (2020, February). Under Ice with the NUI hybrid ROV. In *Ocean Sciences Meeting 2020*. AGU.

German, C. R., **Bowen, A.**, **Jakuba, M.**, **Boetius, A.**, **Schindwein, V. S.**, **Bünz, S.**, and **Ramirez Llodra, E.** (2019, December). Exploring Ice-Covered Oceans, Top to Bottom: Experiences in the Arctic with NUI (5k). In *AGU Fall Meeting Abstracts* (Vol. 2019, pp. P51B-03).

Shank, T. M., **Machado, C.**, **German, C. R.**, **Bowen, A.**, **Leichty, J. M.**, **Klesh, A. T.**, ... and **Hand, K. P.** (2019). Development of a New Class of Autonomous Underwater Vehicle (AUV), Orpheus, for the Exploration of Ocean World Analogues. *Ocean Worlds* 4, 2168, 6021.

Soule, S. A., **Heffron, E.**, **Gee, L.**, **Mayer, L.**, **Raineault, N. A.**, **German, C. R.**, ... and **Parcheta, C.** (2019). Mapping the Lava Deltas of the 2018 Eruption of Kilauea Volcano. *Oceanography*, 32(1).

Soule, S. A., **Zoeller, M.**, and **Parcheta, C.** (2021). Submarine lava deltas of the 2018 eruption of Kilauea volcano. *Bulletin of Volcanology*, 83(4), 1-16.

Dietterich, H. R., **Diefenbach, A. K.**, **Soule, S. A.**, **Zoeller, M. H.**, **Patrick, M. P.**, **Major, J. J.**, and **Lundgren, P. R.** (2021). Lava effusion rate evolution and erupted volume during the 2018 Kilauea lower East Rift Zone eruption. *Bulletin of Volcanology*, 83(4), 1-18.

Raineault, N.A., **J. Flanders**, and **E. Niiler**, eds. 2021. New frontiers in ocean exploration: The E/V *Nautilus*, NOAA Ship *Okeanos Explorer*, and R/V *Falkor* 2020 field season. *Oceanography* 34(1), supplement, 78 pp., <https://doi.org/10.5670/oceanog.2021.supplement.01>.

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