NEW FRONTIERS IN OCEAN EXPLORATION

The E/V *Nautilus*, NOAA Ship *Okeanos Explorer*, and R/V *Falkor* 2020 Field Season

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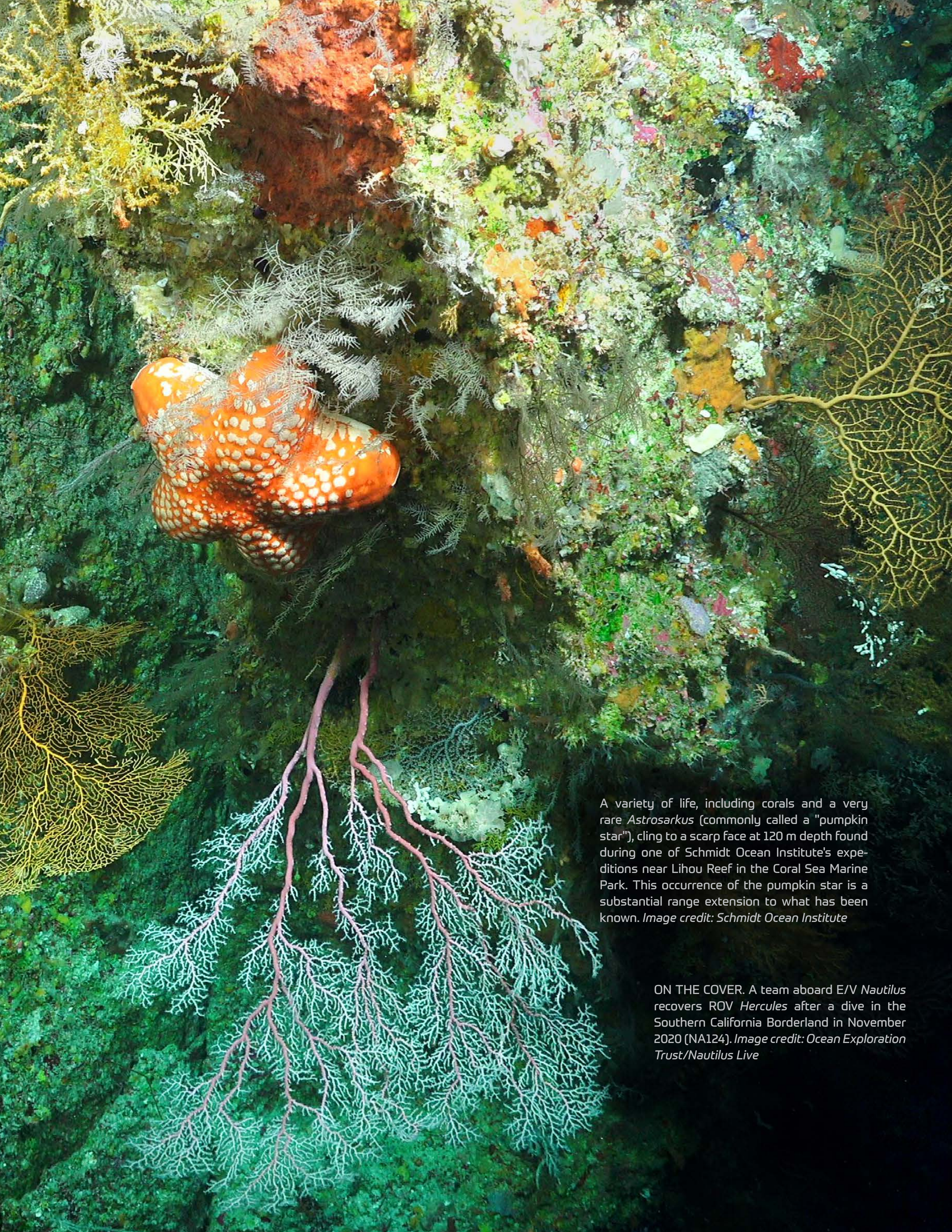

A variety of life, including corals and a very rare *Astrosarkus* (commonly called a "pumpkin star"), cling to a scarp face at 120 m depth found during one of Schmidt Ocean Institute's expeditions near Lihou Reef in the Coral Sea Marine Park. This occurrence of the pumpkin star is a substantial range extension to what has been known. *Image credit: Schmidt Ocean Institute*

ON THE COVER. A team aboard E/V *Nautilus* recovers ROV *Hercules* after a dive in the Southern California Borderland in November 2020 (NA124). *Image credit: Ocean Exploration Trust/Nautilus Live*

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PREFERRED CITATION

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In the deep dark ocean, life seems to attract other life. This small crustacean clings happily to a black coral where it sifts through the food that the water movement delivers, both for the coral and the crustacean. *Image credit: Schmidt Ocean Institute*

INTRODUCTION

By Nicole A. Raineault, Genene Fisher, and Carlie Wiener

This eleventh installment of the annual ocean exploration supplement to *Oceanography*, the official magazine of The Oceanography Society, highlights the work of three vessels that contribute to exploring the world ocean: the Ocean Exploration Trust's (OET's) E/V *Nautilus*, NOAA Ship *Okeanos Explorer*, and Schmidt Ocean Institute's (SOI's) R/V *Falkor*.

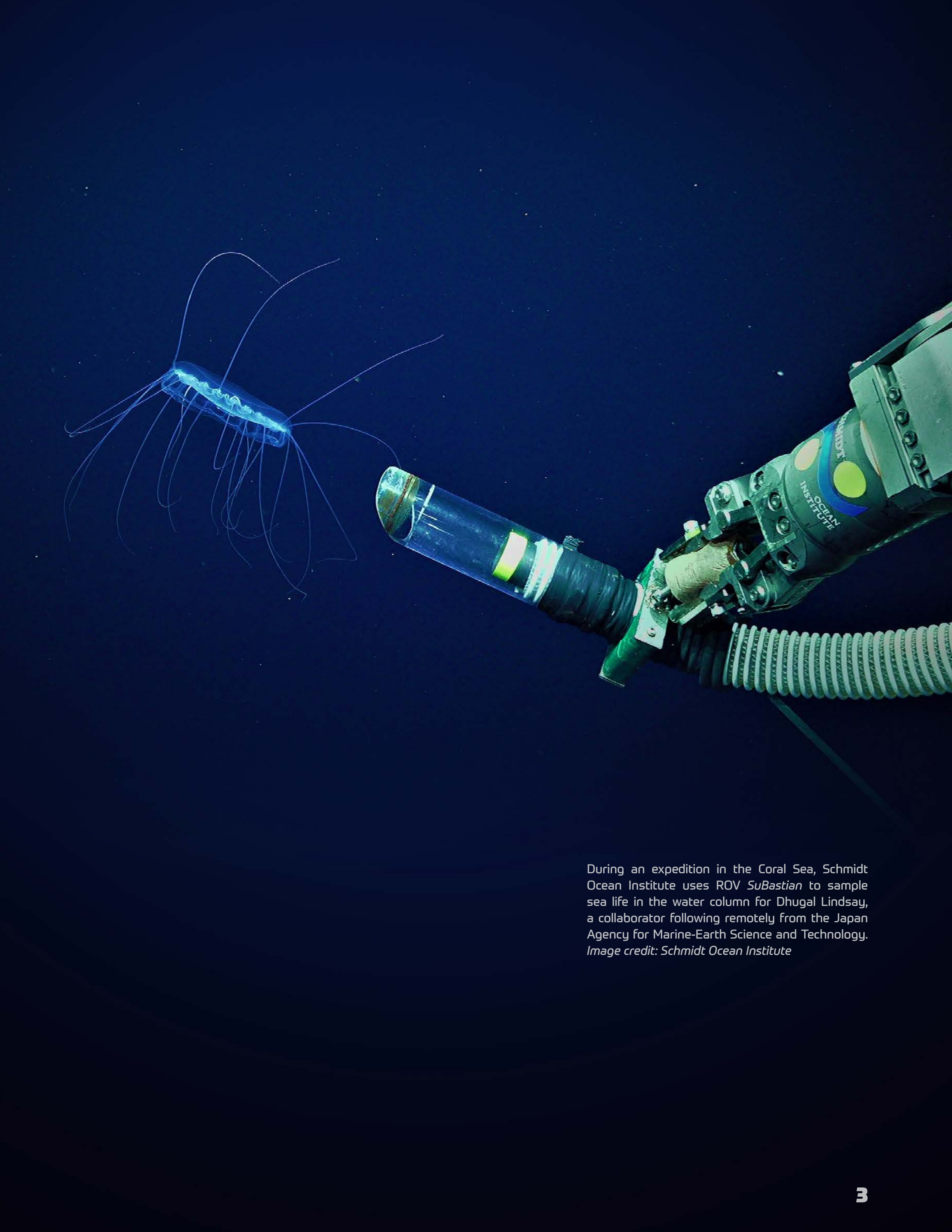
Although the global COVID-19 pandemic impacted the 2020 programs, it did not prevent the execution of significant ocean exploration work, both at sea and on shore. R/V *Falkor* and E/V *Nautilus* took to the seas for modified programs. NOAA paused at-sea operations for *Okeanos Explorer*, with the NOAA Office of Ocean Exploration and Research (OER) instead focusing on development of universal exploration products and enhancement of its virtual engagement efforts. The pages that follow contain summaries of the 2020 expeditions, including initial results; highlights of new programs and initiatives, many of which were catalyzed by the pandemic; and information on future exploration plans.

The first section highlights OET and E/V *Nautilus* programs. The pandemic delayed the start of the season, as the shipyard work to replace the engine was slowed. New mobile control vans and an integrated studio van were also installed and tested before the season got underway in August. The shipboard team size was limited, which meant many dives and entire expeditions were led from shore. OET conducted cabled observatory work in partnership with Ocean Networks Canada and the University of Victoria (pages 30–31). Olympic Coast, Greater Farallones, Monterey Bay, and Channel Islands National Marine Sanctuaries and sites within the proposed Chumash Heritage National Marine Sanctuary were mapped and characterized with remotely operated vehicles (ROVs; pages 32–37). Expeditions focusing on the US blue economy featured ROV dives along the California Borderland and the Cascadia margin, supporting research into the biopharmaceutical/biotechnological possibilities of the deep sea and the broader importance of these areas (pages 32–33 and 38–39). Finally, the NOAA Ocean Exploration Cooperative Institute (OECI) hired a director, Adam Soule, who started work at the University of Rhode Island's Graduate School of Oceanography in January. The institutions involved in this venture have formalized working groups organized to catalyze collaborations in key areas such as science and technology, data management and usability, telepresence technologies, and education and branding. Technologies that will improve our ability to explore the ocean were modified, acquired, or tested and will feature in the *Nautilus* 2021 field season and beyond (pages 40–43).

The second section focuses on the 2020 activities of the NOAA Office of Ocean Exploration and Research. It opens with an overview of the US strategy for ocean exploration that led to OER's creation (page 46–47) and then introduces the new White House *National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone* (NOMEC, 2020) and describes how OER's mission fits within its blueprint (pages 46–47). The section discusses an underlying objective of the National Ocean Mapping, Exploration, and Characterization (NOMEC) Council to expand the US blue economy (pages 48–50), provides examples of OER's grant-supported projects that are tied to the blue economy in the areas of bioprospecting (page 49) and deep-sea methane seeps (page 49), and describes development plans for a long-duration sensor platform (page 50). OER then summarizes work that supports the NOMEC blueprint for exploration and characterization of the US Exclusive Economic Zone (EEZ) and provides examples of the deep-sea products, exploration models, and strategies (pages 51–52) that can be utilized by the broader community. This section also describes a mapping survey conducted in partnership with a commercial firm and designed to accelerate mapping of the EEZ (page 52); its success filled a significant gap in EEZ coverage while advancing objectives of the Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE). OER then discusses the NOMEC objective to build public and private partnerships and inspire and involve the public through such efforts as a matrixed educational program, new professional development offerings for educators, and an expanded internship program (pages 53–54). Next, OER highlights the OER-supported NOMEC objective to develop new and emerging science and mapping technologies and features advancements in telepresence, remote mapping, and autonomous vessel technologies (pages 55–57). This section closes with a quick look at 2021 plans for *Okeanos Explorer*. After a series of shakedowns and sea trials for new mission systems that were installed during the winter repair period, the ship will conduct a technology demonstration as part of OER's commitment to advancing ocean technologies, explore seamounts off New England in support of ASPIRE priorities, and focus on deep-sea mapping offshore the southeastern United States (page 57).

The year 2020 held surprises and discoveries for Schmidt Ocean Institute, as R/V *Falkor* undertook a year-long initiative in waters off Australia. Eight expeditions with interdisciplinary teams of scientists from Australia and around the world allowed for some of the first visualizations of the continent's deep-sea environments (pages 58–67). The collected imagery, samples, and data have important implications for future management decisions within the Coral Sea, Gascoyne, and Great Barrier Reef Marine Parks. Along with the underwater surveys, *Falkor*'s mapping effort will help scientists better understand the Australian continent's formation, history, and how its ecosystems have responded to climatic shifts and tectonic movement in the geologic past. This section highlights the expeditions filled with surprising new species, achievements, and discoveries, including a 500 m tall detached reef in the Great Barrier Reef—the first discovered in this area in the last 120 years.

Exploration in 2021 will capitalize on the groundwork laid this past year by the NOAA Ocean Exploration Cooperative Institute as we apply new technologies and concepts of operation to our expeditions. As this publication went to press, OER welcomed aboard its new Cooperative Institute Manager who will work closely with the OECI host University of Rhode Island and partnership institutions at the University of New Hampshire, the University of Southern Mississippi, the Woods Hole Oceanographic Institution, and the not-for-profit Ocean Exploration Trust. *Nautilus* will explore the waters between the US West Coast and Canada and then move west to continue exploration within the Papahānaumokuākea Marine National Monument and other waters off Hawai'i. *Okeanos Explorer* will conduct a technology demonstration expedition, explore the New England and Corner Rise Seamounts that formed when the North American Plate moved over the Great Meteor hotspot about 75 million years ago, and close gaps in the bathymetric coverage of waters offshore the southeastern United States. An objective of the demonstration is to validate and develop the use of Terrain Relative Navigation with respect to full ocean depth (11,000 m) capable autonomous underwater vehicles. Schmidt Ocean Institute will continue to brave new frontiers in the ocean, pursuing work in Australian waters and the Pacific Ocean with skilled research, community participation, and interdisciplinary collaborations. SOI, OET, and OER are partnering with large-scale international initiatives such as the UN Decade of Ocean Science for Sustainable Development and the Nippon Foundation-GEBCO Seabed 2030 Project. These global campaigns are good examples of how collaboration can lead to broader understanding of our ocean. We are committed to this collaborative work and extremely hopeful about the future.



During an expedition in the Coral Sea, Schmidt Ocean Institute uses ROV *SuBastian* to sample sea life in the water column for Dhugal Lindsay, a collaborator following remotely from the Japan Agency for Marine-Earth Science and Technology. *Image credit: Schmidt Ocean Institute*

Inner Space Center Media Production in the Cloud

Adapting Ocean Science Communication for the 21st Century

By Holly Morin, Alex DeCiccio, Ryan Campos, Jessica Kaelblein, Derek Sutcliffe, and Dwight F. Coleman

The Inner Space Center (ISC) is a leader in using cutting-edge telepresence technologies to support live ocean exploration and connect scientists and other audiences on shore with ocean science activities at sea. During a standard ocean exploration season, the ISC provides telepresence engineering and media production support for vessels such as NOAA Ship *Okeanos Explorer* and E/V *Nautilus* to facilitate, capture, produce, and promote underwater exploration in real time. Although 2020 was a nontraditional exploration season in many ways, the ISC was well positioned to meet many of the challenges associated with remote networking and ocean science engagement during the pandemic.

However, without ship-based communicators to establish an engagement link, the ISC Media and Production Team had to adapt the way in which audiences—science and nonscience—could use telepresence connections and access oceanographic content. The team had to redefine production strategies while working from home and conduct more virtual meetings in the cloud.

Advancing Reach Through Telepresence Technology (ARTT) was the team's first successful demonstration of remote media production. The highly produced video piece, fully created while team members worked entirely at home, was submitted to the US National Science Foundation's (NSF) STEM for All Video Showcase in May 2020. The video highlighted the ocean science research and communication efforts of the NSF-funded Northwest Passage Project (Figure 1). It received over 3,600 views and was awarded a "Presenter's Choice" medal during the Showcase.

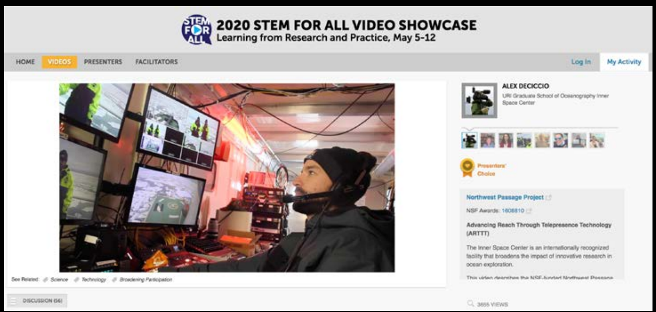


FIGURE 1. Almost a year after successful completion of the Northwest Passage Project, the ISC participated in the NSF STEM for All Video Showcase to share the project's research, student engagement, and science communication techniques with others in the STEM community. Advancing Reach Through Telepresence Technology was entirely produced by the ISC Team while working from home.

To further media and production efforts during the pandemic, the team connected with existing partners to talk about engagement priorities and remote programming considerations. Members of the media and communications industry were also contacted to better understand the production tools and techniques they used for virtual engagement. This initial research was key to developing effective processes for cloud-based media production. New ways of collaboration were realized, and IP-based tools were identified and tested to broadly support the engagement activities of the ocean exploration community.

Software-based IP communications, which maintain content and media assets in the cloud, are less expensive and require less staff time to operate than traditional telepresence practices. These strategies free up resources for other purposes, such as creating targeted programming for specific audiences and achieving continuity across different communication platforms. However, shifting to a more IP-based mode of communication and production is a fundamental shift away from traditional ISC telepresence models, which are built on broadband-based equipment and signal flow as well as high-end broadcast hardware and hub-like facilities to support communication infrastructure.

The ISC tested and invested in multiple pieces of production software to successfully produce engaging and interactive programming in the cloud. Mobile-friendly intercom applications, like Unity Intercom, were utilized for remote communications during live programs. The ease of the modern, web-based, user-friendly platform StreamYard, with an Internet connection as the only requirement, allowed connection to activities with one click.

This more accessible, browser-based entry point increased science communication opportunities with ocean and engineering professionals while not burdening them with the unnecessary weight of managing production elements. Collecting and formatting images and video, building a specific brand for each series or program, displaying and transitioning media during live programs, monitoring audio, tracking audience questions and

FIGURE 2. Remotely operated vehicle pilot and engineer, Jessica Sandoval, speaks as a content expert in a Deep Sea Dialogues video on underwater robotics. In addition to being a stand-alone media piece, the video is also a supporting resource to NOAA OER's virtual professional development programs (supported by the ISC).

FIGURE 3. Hosted by Samantha Wishnak, Communications Manager for the Ocean Exploration Trust, this Next on Nautilus: Channel Islands National Marine Sanctuary and Santa Lucia Bank episode featured the new ship broadcast studio and remote participants, creating a "watch-party" environment between ship and shore.

comments in real time, and sharing questions with hosts and experts during live broadcasts were the responsibility of ISC staff working remotely from home. This enhanced the impact of each program by allowing presenters to focus on telling their stories and engaging with hosts and audiences. Broadcast format transitioned from a more standard, single speaker/presentation style to one that was more interactive and conversation-based (Figure 2).

Guests and hosts alike noted the seamlessness of these programs and appreciated the ease of discussion that took place. The comfort level of teleconferencing helped accelerate the early adoption of these programs in terms of connecting with subject matter experts and sharing their stories from home.

An IP-based approach to interactive programming also allowed ship-based feeds to be incorporated into the same browser-based broadcast studio. This created a unique opportunity for an enhanced "watch-party" environment with video and audio that included select shore-based observers and ship personnel (Figure 3). As IP-based communications replaced certain components of the traditional broadcast environment, ISC production members could also "hot-swap" their roles and responsibilities, even during live programming. Such flexibility allowed for expanded training opportunities for producers and communicators, including those outside the ISC team.

From April through December 2020, the ISC produced and/or hosted over 40 virtual and interactive programs, including 17 Ocean Classroom Live episodes in collaboration with the University of Rhode Island's Graduate School of Oceanography (URI/GSO) (Figure 4). The programs covered topics such as ocean careers, shark behavior and biology, and hurricanes; they aired through outlets such as YouTube and Facebook Live; and they have been archived to these social media platforms as well as the URI/GSO website with associated resources. As of December 2020, the videos have received nearly 10,000 cumulative views on Facebook and over 1,400 views on YouTube.

A few noteworthy lessons were learned during the ISC's dive into IP-based media production from home. The team developed a renewed awareness of the importance of workforce dynamics such as patience, respect, and flexibility. At the same time, effective and consistent communication—both internally and externally—remained a top priority. Each ISC Media and Production project began with a dialogue that focused within a single, shared document. These documents became the framework that guided the development of each program. They also formed the backbone for a new, collaborative process for efficient media production, one that embraces uncertainty and new ideas as well as the free flow of communication.

Although the year 2020 was challenging, the adjustment to working in a virtual environment offered an opportunity to reflect on best practices and improve efficiencies. A new sense of place and potential paradigm shift for ocean exploration media production was recognized in the cloud environment. It is nimble and accessible and highlights the ISC's efforts to embrace modern approaches to communicating science and enabling future capacities for the way people connect to the world of ocean science and exploration.

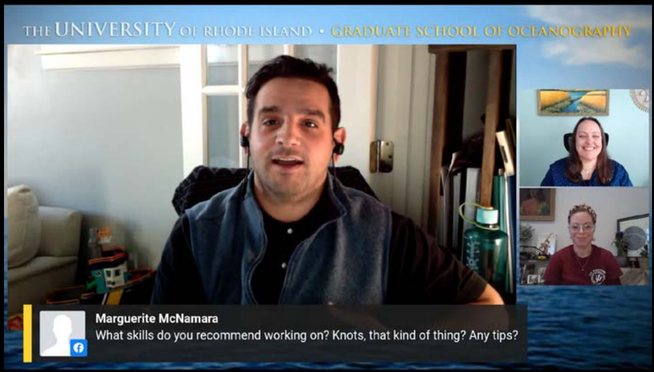
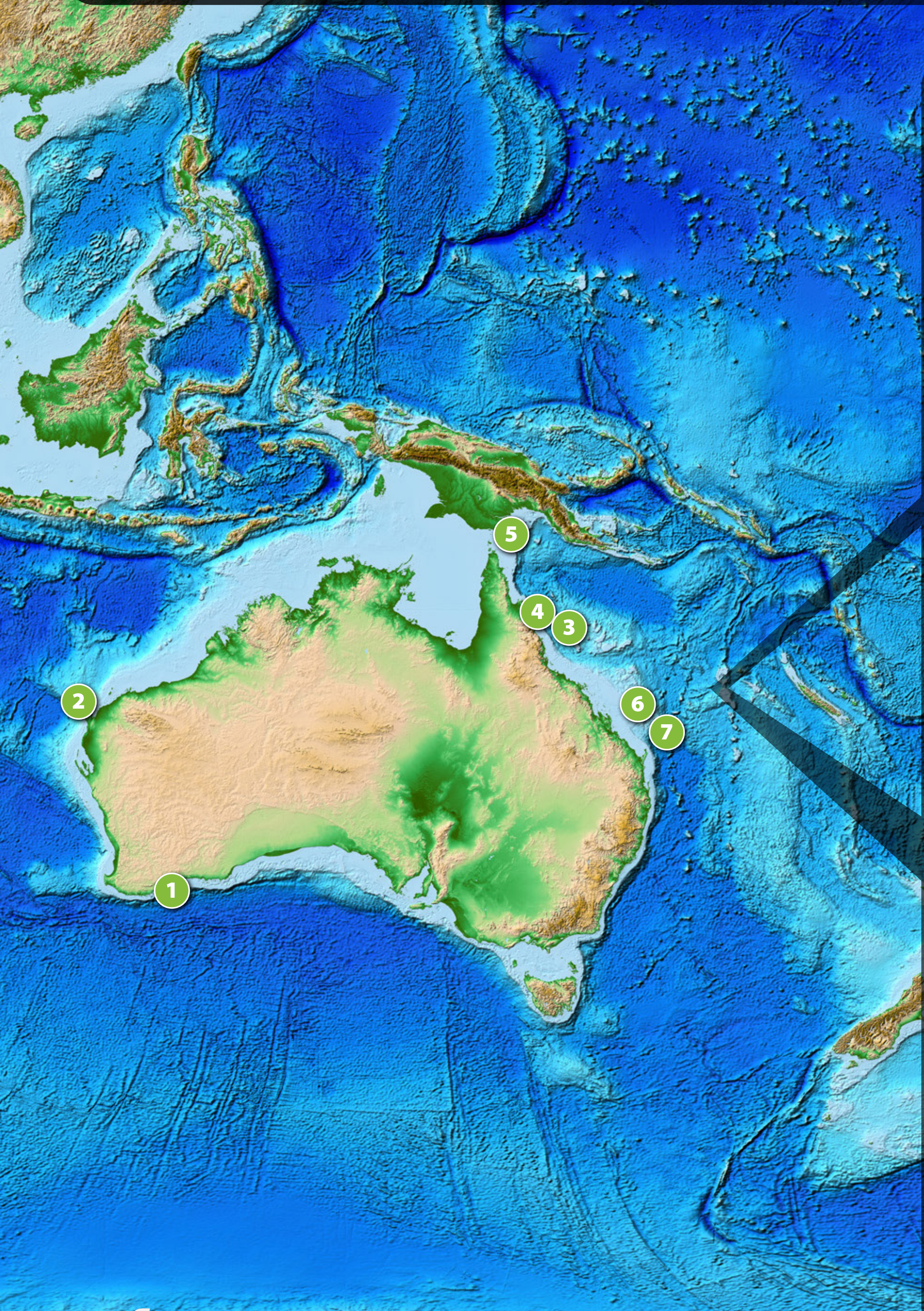


FIGURE 4. During the 16th episode of the URI/GSO's Ocean Classroom Live, the ISC's Alex DeCicco fields audience questions live, with Colleen Peters and Kylie Pasternak of URI/GSO. The focus of this episode was ship-based career stories.



E/V *NAUTILUS* EXPEDITIONS

R/V *FALKOR* EXPEDITIONS

2020 EXPEDITION OVERVIEW MAP

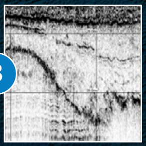
NOAA OFFICE OF OCEAN EXPLORATION AND RESEARCH

1 Page 50
Exploring Wimble Shoals

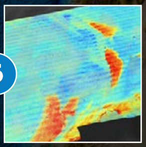
4 Page 49
Bioprospecting in an Ancient Submarine Forest

2 **Exploring Blue Holes**

5 **Southeastern US Deep-Sea Exploration***



3 **Paleolandscapes of the Gulf of Mexico**

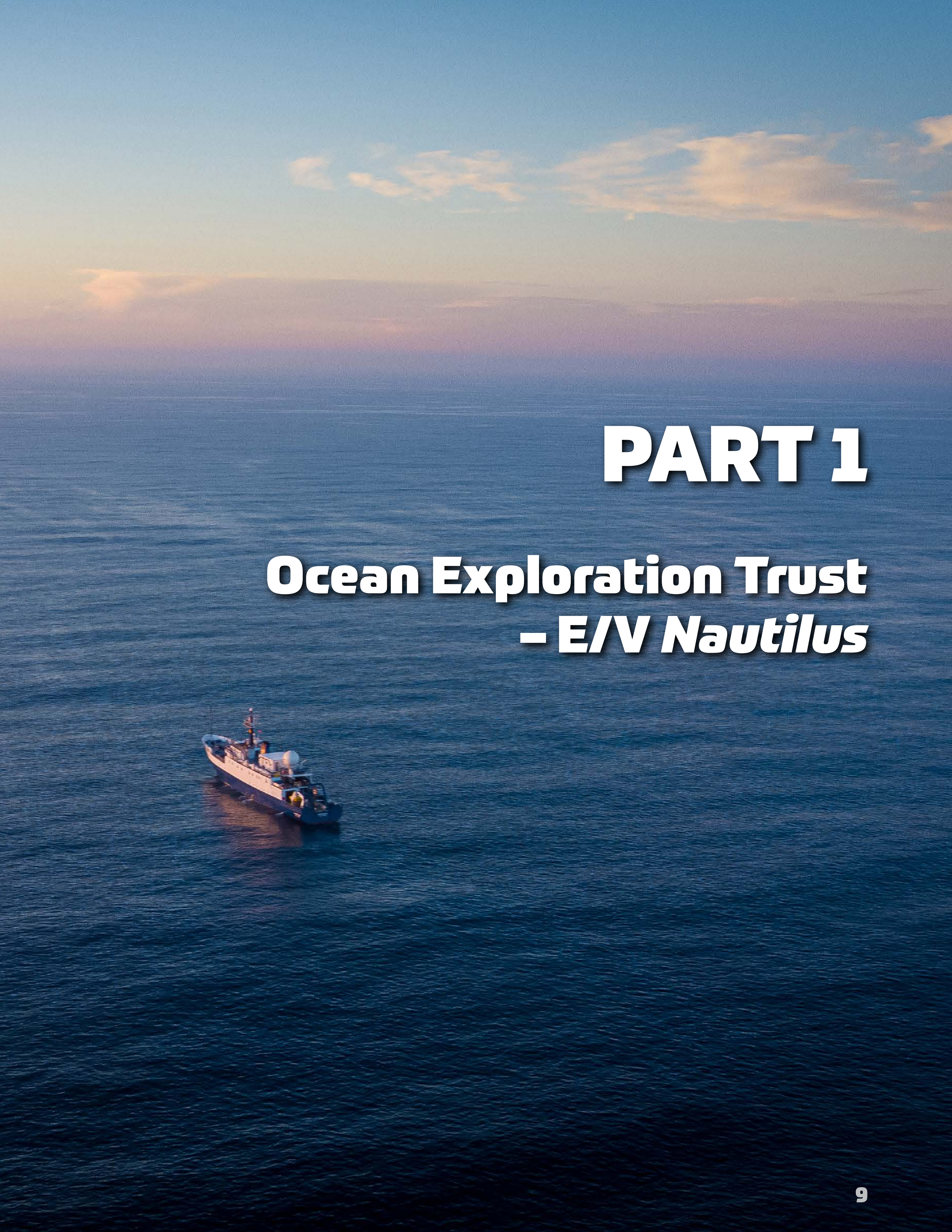


6 Page 52
Fugro Hydrographic Survey*

*ASPIRE

***E/V Nautilus* Expeditions**
NOAA OER also provided support for two 2020 E/V *Nautilus* expeditions to explore *Blue Economic Seep Resources* and *Mineral-Rich Marine Biomes.*

Note: All images in the Nautilus *section of this publication are copyright Ocean Exploration Trust Inc. unless otherwise indicated.*



PART 1

Ocean Exploration Trust – E/V *Nautilus*

TECHNOLOGY

E/V Nautilus

Exploration Vessel (E/V) *Nautilus* is an efficient 64-meter ship, with berthing for 17 permanent crew members in addition to 31 berths for members of the rotating Corps of Exploration. *Nautilus* is equipped with a Kongsberg EM 302 multibeam echosounder and two remotely operated vehicles (ROVs), *Hercules* and *Argus*. The ship has a data lab and newly renovated wet lab for processing digital data and physical samples. As part of the Ocean Exploration Trust's effort to share expeditions with students, public audiences, and colleagues, we utilize telepresence technology to stream live video from the ROVs and various locations aboard the ship in real time to the Nautilus Live website (https://nautiluslive.org).

GENERAL

BUILT. 1967, Rostock, Germany

LENGTH. 64.23 meters (211 feet)

BEAM. 10.5 meters (34.5 feet)

DRAFT. 4.9 meters (14.75 feet)

TONNAGE. 1,249 gross, 374 net

RANGE. 24,000 kilometers (13,000 nautical miles) at 10 knots

ENDURANCE. 40 days at sea

SPEED. 10 knots service, 12 knots maximum

FUEL CAPACITY. 330 cubic meters

PROPULSION. Single 1,285 kilowatt (1,700 hp) controllable pitch main thruster; 280 kW bow tunnel thruster; 300 kW jet pump stern thruster

SHIP SERVICE GENERATORS. Two 585 kVA generators, one 350 kVA generator

PORTABLE VAN SPACE. Three 6.1-meter (20-foot) vans

COMPLEMENT. 17 crew; 31 science and operations

FLAG. St. Vincent and the Grenadines

ADDITIONAL EQUIPMENT

- Dynacon 369i ROV winch with 4,500 meters (14,800 feet) of 1.73 centimeter (0.681 inch) diameter electro-optic Rochester cable
- DT Marine 210 winch
- Bonfiglioli knuckle-boom crane, 2–6 ton capacity, two extensions
- Two airtuggers, SWL 900 lbs each
- A-frame, SWL 8 tonnes
- Two rescue boats; davit with SWL 0.9 mtn
- Oceanscience UCTD 10-400 profiling system; max depth 1,000 meters (3,280 feet)

TELEPRESENCE TECHNOLOGY

VSAT. 2.4 meter stabilized Sea Tel 9711 antenna capable of C- and Ku-band operation of up to 20 Mbps (C-band circular or linear)

REAL-TIME VIDEO STREAMING. Six Haivison Makito X encoders streaming live video via satellite to the Inner Space Center ashore (including spares)

CAMERAS. 21 high-definition cameras: aft port, amid and starboard (pan/zoom/tilt), transom, bow, Command Center (7), wet lab, ROV hangar, winch hold (6)

COMMUNICATIONS

- Ship-wide RTS Odin intercom system for shipboard communications and connection with shoreside participants
- Software audio connection for global participants using VLink multi-platform intercom client (Mac, Windows, Android, iOS); telephone interface is available through a Rhode Island exchange for real-time collaboration between scientists ashore and on the ship
- Full Internet connectivity from shipboard LAN and wifi
- KVH TracPhone-v7 for redundant bridge communication, providing telephone and IP service

DATA PROCESSING & VISUALIZATION LAB

AREA. 44.5 square meters (480 square feet)

WORKSTATIONS. Seven workstations for science managers, data loggers, navigators, educators, data engineers, satellite engineer, video engineer; seafloor mapping data processing; flexible bench space

RACK ROOM

AREA. 17.3 square meters (185 square feet)

DATA STORAGE. 29 TB onboard storage for non-video data; 150 TB disk storage for video data

EMERGENCY COMMUNICATIONS. Iridium phone, KVH phone

ELECTRONICS WORKBENCH. 2.3 cubic meters (80 cubic feet) of storage

PRODUCTION STUDIO

AREA. 12 square meters (130 square feet)

CAMERA. Remote controllable high-definition Sony BRC-H700 in studio, Canon FX-305 for live deck television broadcasts

PRODUCTION. 8-input video production switcher for live-produced interactions; mobile laptop unit for ship workspace interactions

WET LAB

AREA. 19 square meters (204.5 square feet) with 5.3-meter-long (17.5-foot) stainless steel bench and 2.3-meter-long (7.6-foot) worktop

REFRIGERATION

- Panasonic MDF-C8V1 ULT –80°C/–86°C scientific freezer, 0.085 cubic meters (3 cubic feet)
- Two scientific refrigerators, approximately 0.57 cubic meters (20 cubic feet) each
- Two –20°C scientific freezers, 0.14 cubic meters and 0.20 cubic meters (5 cubic feet and 7 cubic feet)

HAZMAT

- Fume hood
- Two HAZMAT lockers for chemical and waste storage
- Carry-on, carry-off chemical policy

ROV HANGAR

AREA. 24 square meters (258.3 square feet)

POWER. 110/60 Hz and 220/50 Hz available

PERSONAL PROTECTIVE EQUIPMENT. Hard hats, PFDs, high voltage gloves

LIFTS. 2 × 2-ton overhead manual chainfall lifts

STORAGE. Storage for spares and other equipment

ROV WORKSHOP

AREA. 18 square meters (193.8 square feet)

TOOLS. Complete set of hand tools, cordless tools, electrical and fiber optic test equipment, mill-drill combination machine

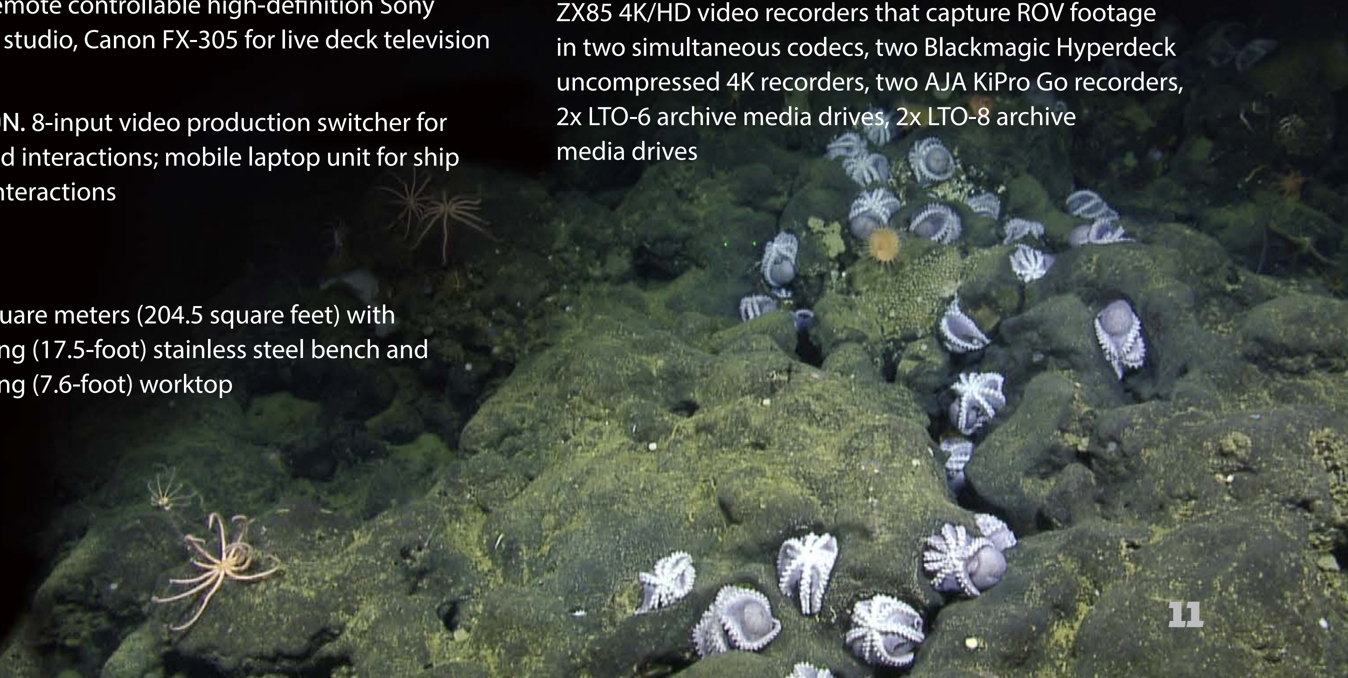
STORAGE. Storage for spares and other equipment

CONTROL, COMMAND, & OUTREACH VANS

AREA. 43 square meters (476 square feet)

WORKSTATIONS. Twelve; typical configuration for ROV operations: two to three scientists, data logger, pilot and copilot, navigator, video engineer, educator

VIDEO RECORDING AND STORAGE. Two Cinedeck ZX85 4K/HD video recorders that capture ROV footage in two simultaneous codecs, two Blackmagic Hyperdeck uncompressed 4K recorders, two AJA KiPro Go recorders, 2x LTO-6 archive media drives, 2x LTO-8 archive media drives



Acoustic Systems

KONGSBERG EM 302 MULTIBEAM ECHOSOUNDER

The EM 302 is a hull-mounted 30 kHz multibeam echosounder composed of two long transducer arrays mounted in a T-shape on the hull of *Nautilus*. It was installed on the ship between 2012 and 2013 to collect bathymetric, backscatter, and water column data. This information is useful for identifying areas or features of interest, including gas seeps, and creating bathymetric maps for ROV dive planning and situational awareness. The EM 302 can map the seafloor in water depths from 10 meters to 7,000 meters (33 feet to 22,965 feet) at ship speeds up to 12 knots.

FREQUENCY. 30 kHz

DEPTH RANGE. 10–7,000 meters (33–22,966 feet)

PULSE FORMS. CW and FM chirp

BEAMWIDTH. 1° × 1°

APPROXIMATE SWATH WIDTH. 3–5 times water depth, up to 8 kilometers (5 miles)

APPROXIMATE GRID RESOLUTION. 10% water depth (e.g., 10 meters [33 feet] at 1,000 meters [3,281 feet] depth)

KNUDSEN SUB-BOTTOM PROFILER AND ECHOSOUNDER

The Knudsen 3260 is a sub-bottom echosounder mounted inside the hull of *Nautilus*. It operates at low frequencies (3.5/15 kHz) so that the sound it emits can penetrate layers of sediment to about 100 m below the surface. The sound that bounces back from each layer is captured by the system, creating a cross section of the seafloor. Scientists can use the data to identify subsurface geological structures such as faults and ancient channels and levees. The Knudsen 3260 can operate in full ocean depths. The Knudsen system also collects 15 kHz single-beam echosounding data.

PROFILER. Knudsen 3260 Chirp sub-bottom profiler and echosounder

OPERATING FREQUENCY. Dual frequency, 3.5 kHz and 15 kHz

POWER. 4 kW on Channel 1 and up to 2 kW on Channel 2

RANGE. 50–5,000 meters (164–16,404 feet)

ULTRA-SHORT BASELINE NAVIGATION SYSTEM

SYSTEM. TrackLink 5000MA system for USBL tracking of ROVs *Hercules* and *Argus*

RANGE. Up to 5,000 meters (16,404 feet)

POSITIONING ACCURACY. 1° (~2% of slant range)

OPERATIONAL BEAMWIDTH. 120°

OPERATING FREQUENCY. 14.2–19.8 kHz

TARGETS TRACKED. *Hercules*, *Argus*, and two additional transponders are available. With more transponders, up to eight targets including the ROVs can be tracked.

Remotely Operated Vehicle (Towsled) *Argus*

ROV *Argus* was first launched in 2000 as a deep-tow system capable of diving to 6,000 meters. *Argus* is mainly used in tandem with ROV *Hercules*, where it hovers several meters above in order to provide a bird's-eye view of *Hercules* working on the seafloor. *Argus* is also capable of operating as a stand-alone system for large-scale deepwater survey missions.

GENERAL

DEPTH CAPABILITY. 6,000 meters (19,685 feet), currently limited to 4,000 meters (13,123 feet)

CABLE. 4,500 meters (14,764 feet), 0.681 electro-optical, 3x #11 conductors, 3x SM fibers

SIZE. 3.8 meters long × 1.2 meters wide × 1.3 meters high (12.5 feet long × 3.9 feet wide × 4.3 feet tall)

WEIGHT. 2,100 kilograms (4,700 pounds) in air, 1,360 kilograms (3,000 pounds) in water

MAXIMUM TRANSIT SPEED. 2 knots

ASCENT/DESCENT RATE. 30 meters/minute (98 feet/minute) max

PROPULSION. Two Tecnadyne Model 1020 thrusters for heading control

IMAGING & LIGHTING

CAMERAS

- One Insite Pacific Zeus Plus high-definition camera with Ikegami HDL-45A head and Fujinon HA 10 × 5.2 lens, 1080i SMPTE 292M output format, 2 MP still image capable on tilt platform
- Three utility cameras (fixed mounted) 480 line NTSC format
- One DeepSea Power & Light Wide-i SeaCam, downward-looking standard definition camera (fixed mounted)

LIGHTING

- Three CathX Aphos 16 LED lampheads, 28,000 lumens each
- Two DeepSea Power & Light 250 Watt incandescent lights

VEHICLE SENSORS & NAVIGATION

SYSTEM. NavEst integrated navigation system solution

USBL NAVIGATION. TrackLink 5000 system, acoustically triggered

PRIMARY HEADING. Crossbow high-resolution magnetic motion and attitude sensor

SECONDARY HEADING. Lord Microstrain 3DM-GX5-25 Attitude and Heading Reference System (AHRS)

PRESSURE SENSOR. Paroscientific Digiquartz 8CB series

ALTIMETER. Benthos PSA-916

FORWARD-LOOKING SONAR. Mesotech 1071, 675 kHz, 0.5–100 meter (1.6–328.1 foot) range typical

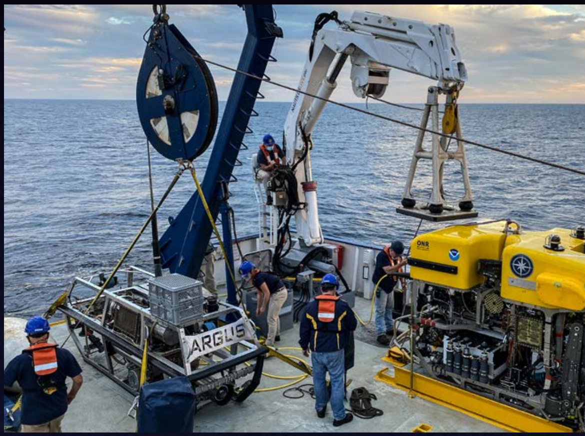
SUB-BOTTOM PROFILING SONAR. TriTech SeaKing Parametric Sub-bottom Profiler (10–30 kHz)

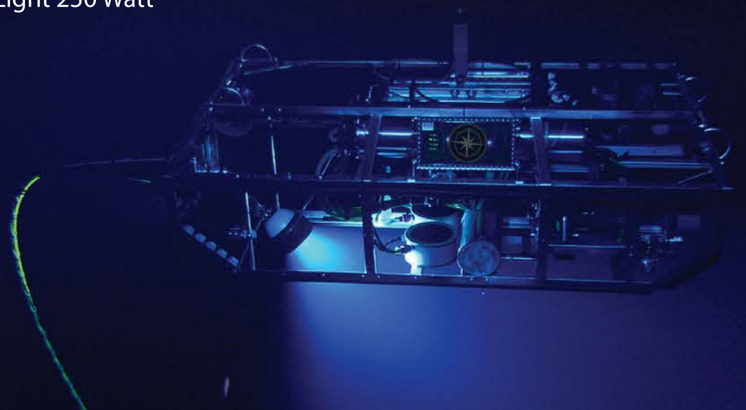
SIDE-SCAN SONAR. EdgeTech 4200 MP (300/600 kHz)

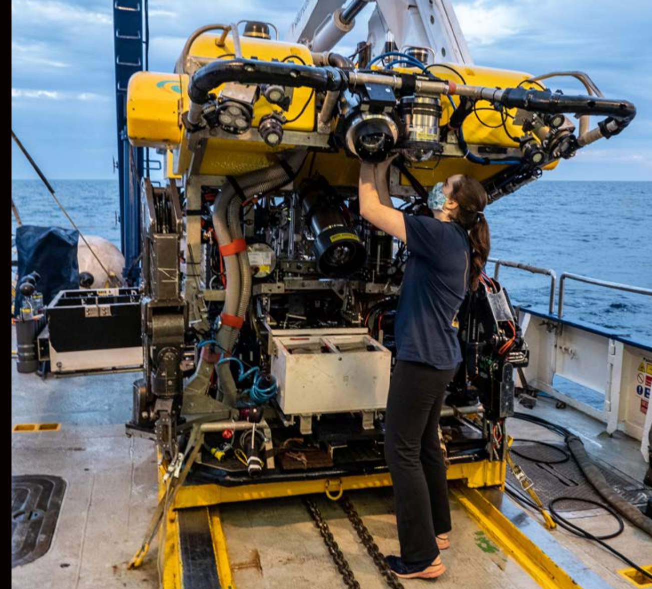
SCIENTIFIC INSTRUMENT SUPPORT

POWER. 110 V 60 Hz AC, 24 VDC and 12 VDC power options

DIGITAL DATA CHANNELS. Ethernet







Remotely Operated Vehicle *Hercules*

Since it was first launched in 2003, ROV *Hercules* has been working in tandem with ROV *Argus* to explore the geology, biology, archaeology, and chemistry of the deep sea. *Hercules* is equipped with a high-definition video camera, several LED lights, two manipulator arms, and a variety of oceanographic sensors and samplers. A suite of high-resolution mapping tools is available for use upon request. *Hercules* can deliver up to 113 kg (250 lbs) of samples or tools to and from the seafloor.

GENERAL

DEPTH CAPABILITY. 4,000 meters (13,123 feet)

TETHER. 30–45 meters (98.4–147.6 feet), 20 millimeters (0.79 inches) diameter, neutrally buoyant

SIZE. 3.9 meters long × 1.9 meters wide × 2.2 meters tall (12.8 feet long × 6.2 feet wide × 7.2 feet tall)

MASS. ~ 2,500 kilograms (5,500 pound) mass in air

PAYLOAD. Up to 113 kilograms (250 pounds)

MAXIMUM VEHICLE SPEED. 0.77 meters/second (1.5 knots) forward, 0.25 meters/second (0.5 knots) lateral, 0.5 meters/second (1 knot) vertical (on site, within tether range)

MAXIMUM TRANSIT SPEED. 1 meter/second (2 knots), no sampling, in layback mode

MAXIMUM ON-BOTTOM TRANSIT SPEED
0.5 meters/second (1 knot), no sampling

MAXIMUM SAMPLING TRANSIT SPEED
0.25 meters/second (0.5 knots) on flat seafloor;
<0.13 meters/second (<0.25 knots) over featured terrain

ROV CLOSED LOOP POSITION CONTROL
Station Keep, X/Y step, Auto Depth, Auto Altitude, X/Y/Z step and hold velocity control

DESCENT/ASCENT RATE. 30 meters/minute (98.4 feet/minute), 15 meters/minute (49.2 feet/minute), or 20–22 meters/minute (65.6–7.2 feet/minute) average

PROPULSION
- Six hydraulic thrusters powered by 15 kW (20 hp), 207 bar (3,000 psi) hydraulic system
- Fore/Aft & Vertical – Four 27.94 cm (11 inch) ducted thrusters, each providing 900 N (200 lbf) thrust
- Lateral – Two 22.86 cm (9 inch) ducted thrusters, each providing 450 N (100 lbf) thrust

VEHICLE SENSORS & NAVIGATION

SYSTEM. NavEst integrated navigation system solution

HEADING AND ATTITUDE
- Primary Heading – IXSEA Octans III north-seeking fiber-optic gyrocompass (0.1° secant latitude accuracy with 0.01° resolution)
- Secondary Heading – TCM2 solid state fluxgate compass

PRESSURE SENSOR. Paroscientific Digiquartz 8CB series

CTD. Sea-Bird FastCAT 49

OXYGEN OPTODE. Aanderaa 3830

TEMPERATURE PROBE. WHOI high-temperature probe (0°–450°C, 0.1°C resolution)

DOPPLER NAVIGATION & ALTITUDE. RDI Workhorse Navigator Doppler Velocity Log 600 kHz, 0.7–90 meter range (2.3–295.3 feet)

FORWARD-LOOKING SONARS
- Kongsberg Mesotech 1071 scanning sonar, 300 kHz, 1–200 meter (3–656 feet) range typical
- TriTech Super SeaPrince 675 kHz, 50 meter (164 feet) range

IMAGING & LIGHTING

STANDARD IMAGING SUITE. One high-definition video channel on fiber optic, four standard definition video channels on coax, generally configured as:
- Insite Pacific, 6,000 msw rated, Zeus Plus with 10× zoom lens, Ikegami HDL-45A with zoom/pan/tilt/extend, 1080i SMPTE 292M output format
- Insite Pacific, 6,000 msw rated, Titan Rotate-Tilt standard definition camera (bubble camera) 480 line NTSC format

- Three Insite Pacific NOVA utility cameras, mounted to view the starboard sample box, port rail, and aft region 480 line NTSC format
- One Insite Pacific Aurora utility camera to view the eight-jar suction sampler, NTSC format
- One DeepSea Power & Light Wide-i-SeaCam to view starboard side sample box, NTSC format

LIGHTING
- Two DeepSea Power & Light Matrix-3 LED lamps, 20,000 lumens, forward mounted
- Six to twelve DeepSea Power & Light SeaLite Sphere LED lights, 6,000 lumens, mounting configurable

SCALING. Two green DeepSea Power & Light Micro Sea-Lasers, mounted 10 cm (3.94 inches) apart, HD camera only

HIGH-RESOLUTION MAPPING SUITE
- Available for nonstandard mapping products
- Typical configuration is downward looking; forward-looking configuration possible
- Two stereo Prosilica GT 2750 still cameras, one black & white, one color; 2,750 × 2,200 pixels; 29° × 39° field of view; 2–4 meter (6.5–13 feet) range; 200 watt-second strobe lighting at one image every three seconds
- Structured light laser system with a dedicated Prosilica GC 1380 still camera; runs concurrently with stereo imaging; 532 nanometer, 100 mW coherent laser; 45° line generating head
- System also supports Norbit WBMS sonar – forward or downward facing

MANIPULATORS AND SAMPLING

MANIPULATORS
- Kraft Predator: Hydraulic, seven function spatially correspondent, force feedback, 200 lb lift
- ISE Magnum: Hydraulic, seven function, 300 lbs lift

SUCTION SYSTEMS
- Suction sampling system, eight 3-liter discrete samples
- Venturi dredge excavation system

SAMPLING TOOLS. Mission configurable:
- Up to eight 6.35 centimeter (2.5 inch) inner diameter, 28 centimeter (11 inch) long push cores
- Up to six 5-liter Niskin bottles, manually triggered
- Custom tools and sensors can be integrated

SAMPLE STORAGE
- Forward sample tray (inboard): 45 cm × 33 cm × 25 cm (17.7 inches × 13 inches × 9.8 inches)
- Forward sample tray (outboard): 68 cm × 35 cm × 30 cm (26.8 inches × 13.8 inches × 11.8 inches)
- Starboard sample drawer: 65 cm × 50 cm × 30 cm (25.5 inches × 19.7 inches × 11.8 inches)
- Payload: Up to 113 kilograms (250 pounds) depending on sensor package
- Custom configuration of boxes, crates, and containers

SCIENTIFIC INSTRUMENT SUPPORT

SWITCHED POWER
- 110 V, 60 Hz AC
- 24 VDC
- 12 VDC

DIGITAL DATA CHANNELS
- RS-232: 115 Kbauds
- RS-485/422: 2.5 Mbauds
- Ethernet: 10/100/1,000 Mbps links available
- TTL: one TTL link

HYDRAULIC. Proportional and solenoid hydraulic functions:
- 1,150 psi at 5 GPM
- 1,850 psi at 5 GPM
- 3,000 psi at 5 GPM (advance notice needed)

EXAMPLES OF USER-INSTALLED TECHNOLOGY

Advance notice is required for custom solutions to engineering integration of user-provided sensors and equipment.
- In situ mass and laser spectrometers
- Fluorometer, pH sensor, eH sensor
- Kongsberg M3 multibeam sonar
- 18 MP Ethernet connected digital still camera
- Low-light camera
- Modular soft grippers

Remotely Operated Vehicle (Towsled) *Atalanta*

Atalanta was first launched in 2019 and is a smaller version of *Argus*. It is used in tandem with ROVs *Little Hercules* or *Hercules*, hovering several meters above in order to provide a bird's-eye view of the ROV working on the seafloor. *Atalanta* is also capable of operating as a stand-alone system for wider-scale deepwater survey missions.

GENERAL

DEPTH CAPABILITY. 6,000 meters (19,685 feet)

SIZE. 2.16 meters long × 1.0 meters wide × 1.2 meters tall

WEIGHT. 1,000 kg (2,200 pounds) in air;
1,700 pounds in water

MAXIMUM TRANSIT SPEED. 2 knots

ASCENT/DESCENT RATE. 20–30 meters/minute (65–98 feet/minute) max

PROPULSION. Two Tecnadyne Model 1020 1 HP thrusters for heading control

IMAGING & LIGHTING

CAMERAS

- One Insite Pacific Mini Zeus high-definition camera
- Two mini utility cameras (fixed mounted) 480 line NTSC format

LIGHTING

- Eight DeepSea Power & Light (LED) SeaLite LSL-1000 sphere lights

VEHICLE SENSORS & NAVIGATION

HEADING. Lord Microstrain 3DM-GX5-25 Attitude and Heading Reference System (AHRS)

PRESSURE SENSOR. Paroscientific Digiquartz 8CB series

ALTIMETER. Valeport VA500 500Khz Altimeter

FORWARD-LOOKING SONAR. Mesotech 1071, 675 kHz, 0.5–100 meter range typical

SIDE-SCAN SONAR. Edgetech 2205, 75/410 kHz

SCIENTIFIC INSTRUMENT SUPPORT

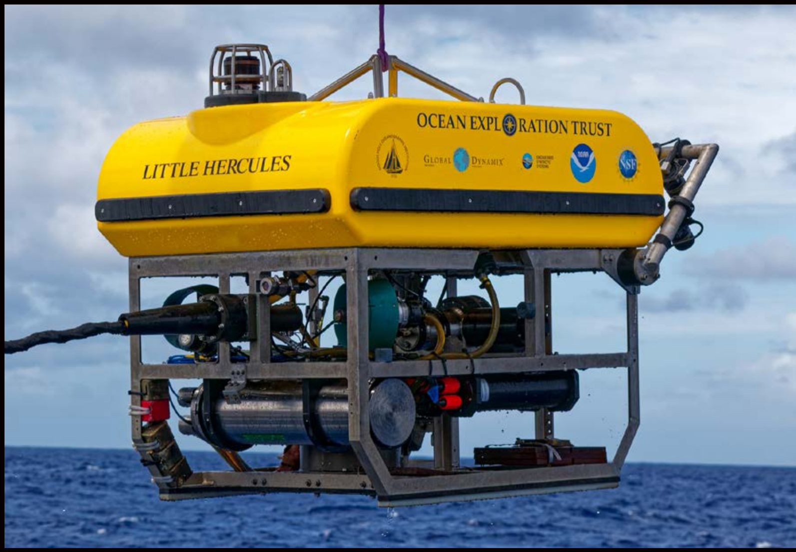
POWER. 110 V 60 Hz AC, 24 VDC and 12 VDC power options

DIGITAL DATA CHANNELS. Ethernet, RS-232

2020 TECHNOLOGY COLLABORATIONS

- OREGON STATE UNIVERSITY. Sexton still camera
- MBARI. Oxygen optode wand
- UNIVERSITY OF RHODE ISLAND. Deepi camera, squishy fingers
- UNIVERSITY OF RHODE ISLAND AND UNIVERSITY OF NEW HAMPSHIRE. Norbit WBMS sonar
- UNIVERSITY OF WASHINGTON. Biogeochemical Argo floats

Remotely Operated Vehicle *Little Hercules*



ROV *Little Hercules* is a smaller sister to *Hercules,* designed to function similarly with *Argus* or *Atalanta* but with a focus on gathering high-quality video imagery. *Little Hercules* is equipped with a high-definition or 4K video camera, LED lights, and basic sensors for navigation and situational awareness. *Little Hercules* was originally built in 2000, and was extensively refurbished and upgraded to 6,000-meter capability in 2019.

GENERAL

DEPTH CAPABILITY. 6,000 meters (19,685 feet)

TETHER. 30–45 meters (98.4–147.6 feet), 20 millimeters (0.79 inches) diameter, neutrally buoyant

SIZE. 1.4 meters long × 1.0 meters wide × 1.2 meters tall

WEIGHT. 400 kilograms (900 pounds) in air; 100 lbs payload

MAXIMUM TRANSIT SPEED. 2 knots

ASCENT/DESCENT RATE. 20–30 meters/minute, (65–98 feet/minute) max

PROPULSION. Four Tecnadyne Model 1020 thrusters for heading control

IMAGING & LIGHTING

CAMERAS

- High definition or ultra high definition
- Two mini utility cameras (fixed mounted) 480 line NTSC format

LIGHTING

- Four Deepsea Power & Light LED sphere lights

VEHICLE SENSORS & NAVIGATION

HEADING. Lord Microstrain 3DM-GX5-25 Attitude and Heading Reference System (AHRS)

PRESSURE SENSOR. Paroscientific Digiquartz 8CB series

ALTIMETER. Valeport VA500 500Khz altimeter

FORWARD-LOOKING SONAR. TriTech Super SeaPrince 675 kHz, 50 meter (164 feet) range

SCIENTIFIC INSTRUMENT SUPPORT

POWER. 110 V 60 Hz AC, 24 VDC and 12 VDC power options

DIGITAL DATA CHANNELS

- RS-232 serial
- Ethernet: 10/100/1,000 mbps links available

ROV POSITIONING

The ROV systems are outfitted with an ultrashort baseline (USBL) navigation system compatible with the operational platform and scientific requirements.

USBL NAVIGATION. Sonardyne Ranger II or TrackLink 5000

MICROBES TO MICROPLASTICS

E/V *Nautilus* Expedition Samples in 2020

By Nicole A. Raineault, Kate Kucharzyk, Taylorann Smith, Daniel Geiger, and Greg Rouse

Extraordinary collaboration and organization resulted in greater sampling outcomes in 2020 despite pandemic-related shipboard staffing restrictions. Five ROV expeditions accommodated requests for over 600 specimens as well as a wider variety of samples for several expeditions. The scientific community's requests were organized into a single West-Coast-wide sample list so that progress could be tracked for each cruise. Meredith Everett, a shoreside watch lead, and Steve Auscavitch, science manager aboard *Nautilus*, coordinated the list, which included images of various fauna in situ to guide the watchstanders. Scientists requesting ocean acidification and particulate organic matter samples sent detailed protocols or videos to aid in the shipboard sample preparation. Other researchers sent gear and preservatives, which were generously shared across different research groups. We accommodated two new types of sampling requests—one for coral and sponge samples to be used in food web analysis and another for live and fossilized cup coral for use in climate studies—along with standard geological and biological vouchers, DNA, and eDNA specimens. Some new research based on 2020 collections is highlighted below.

MICROPLASTIC POLLUTANTS IN DEEP-SEA NATIONAL MARINE SANCTUARIES

– Taylorann Smith and Kate Kucharzyk

The presence of microplastics in the deep ocean creates risk to ecosystem health mainly through ingestion. To support two research initiatives that are seeking to understand plastics pollution, water, sediment, and organism samples were collected across the Channel Islands, Monterey Bay, and the proposed Chumash Heritage National Marine Sanctuaries.

The first program observed drift kelp on the seafloor and collected samples as an extension of Smith's master's research studying microplastics in kelp forest ecosystems. Because the structure of the kelp *Macrocystis pyrifera* is thick, textured, and covered in mucus, it may accumulate and serve as a vector for microplastics throughout marine systems (Figure 1). To identify the concentrations and types of microplastics associated with different water mass properties, water samples were collected at different depths. Organisms utilizing various feeding mechanisms, including sea pens and sea urchins, were collected to identify the concentrations and types of microplastics ingested. Sediment cores and Niskin bottle samples were collected to compare the types of microplastics present in the environment to those within the organisms. Organic material will be removed from organisms, and tissues will be filtered and viewed under a dissecting microscope to count the microplastics. Micro-FTIR will be used to determine the types of plastics. This interdisciplinary work will provide information that could help policymakers implement solutions to the now widely recognized plastics problem.

The second program focused on microbial life and its capability to degrade microplastics. This study is a part of a larger Circular Plastics Campaign at Battelle Memorial Institute and will help scientists validate a unified platform to determine markers of microplastics and hydrocarbon degradation in the deep ocean using a suite of analytical tools. Molecular diagnostics will help answer questions on microbial identity and capability to degrade plastics in the ocean, and Raman spectroscopy will help assess the spatial resolution of microplastics in sediment. These tools allow robust characterization of microbial activities and may reveal new microorganisms or metabolites/enzymes involved in plastics biodegradation. Resulting evidence of microorganismal ability to degrade microplastics and plastics-adsorbed pollutants will inform modeling of the persistence of hydrocarbons and plastics, as well as the bioaccumulation risks associated with microplastics, in deep ocean benthos.

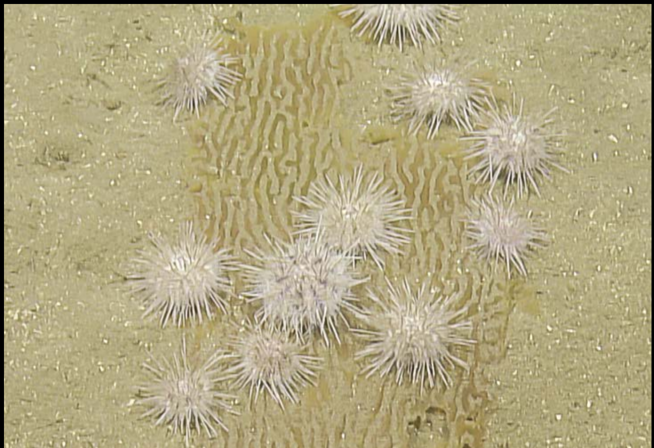


FIGURE 1. Sea urchins feeding on *Macrocystis pyrifera* drift kelp.

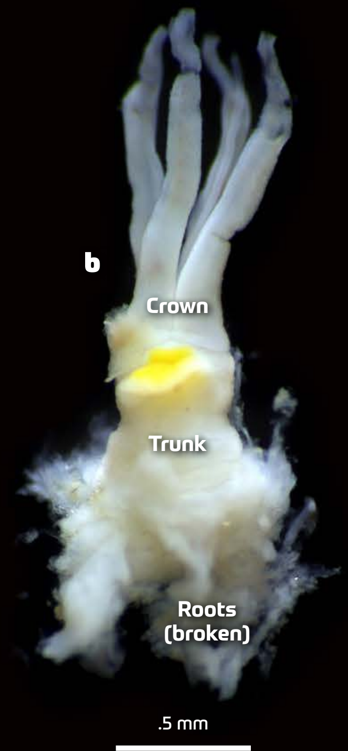
FIGURE 2. *Terebratulina kiiensis* (Dall & Pilsbry, 1891) (SBMNH 650639, NA123-131) from off of southeast Santa Cruz Island, 809 m depth. *Image credit: Vanessa Delnavaz*

MICROINVERTEBRATES FROM SEDIMENT SAMPLES – Daniel Geiger

Deep-sea microinvertebrates are even less well understood than their larger counterparts, as they frequently fall through collection nets. Seventeen sediment samples were collected with scoop, core, or slurp, yielding 26 quart jars of material. Some larger specimens of special interest to Santa Barbara Museum of Natural History researchers were also gathered, including three lots of Brachiopoda, larger snails (*Bathybembix bairdii, Neptunea amianta, Calliostoma variegatum*), large clams (*Acesta sphonii*), and a mystery brachiopod/bivalve specimen, unidentifiable from video footage, that turned out to be the clam *Dimya californiana*. From video footage, the Brachiopoda appeared to be *Laqueus californicus*, but upon closer inspection turned out to be very finely sculptured *Terebratulina crossei* and *T. kiiensis*, as identified by our brachiopod expert Vanessa Delnavaz (Figure 2). We have started the long and laborious process of sorting the sand samples, prioritizing the deepest sample from 3,500 m. Six bivalve species were recovered (one providing a new shallowest record for the species), one small snail of unknown identity, and surprisingly even one (maybe two) caprellid isopods on mud bottom. Foraminifera were the most diverse, with an estimated dozen species in a relatively small sample, plus a good number of amphipods. Thus far, 53 lots have been catalogued, which is but a very small fraction of the ultimate number of lots to be incorporated. All those specimens will be accessible through the Santa Barbara Museum of Natural History online data portal (http://www.sbizcollections.org/iz/) as well as through the iDigBio portal (https://www.idigbio.org/portal/search).

WHALEBONE-EATING WORMS – Greg Rouse

With the permission of NOAA's National Marine Fisheries Service, slurp samples of friable bone pieces and a whole bone, likely a humerus, were collected from a whale fall discovered on cruise NA117 in 2019. The mature minke whale skeleton had significantly degraded in the year since the initial visit, likely in part owing to the action of bone-eating annelid worms of the genus *Osedax*. *Osedax* access the collagen matrix of the bone by secreting acid from root-like tissues. They then consume the collagen with the aid of symbiotic bacteria. This softening and opening up of the bone means the skeleton will break down much faster. Eighteen species of *Osedax* have been named from California to date. On the initial visit, some bone pieces with large *Osedax* had been preserved in ethanol, and they proved, via DNA analysis, to be a new species. Initial study of some bone pieces from the 2020 cruise suggests there are two other *Osedax* species that may also be new because this whale fall is the deepest to be studied to date in the eastern Pacific (Figure 3). DNA sequencing is underway to assess this possibility. Several other annelid worms were also collected and will be studied. The humerus, still covered with the large species of *Osedax*, was deep frozen and awaits thawing and dissection to remove them before sending the bone to the California Academy of Sciences.



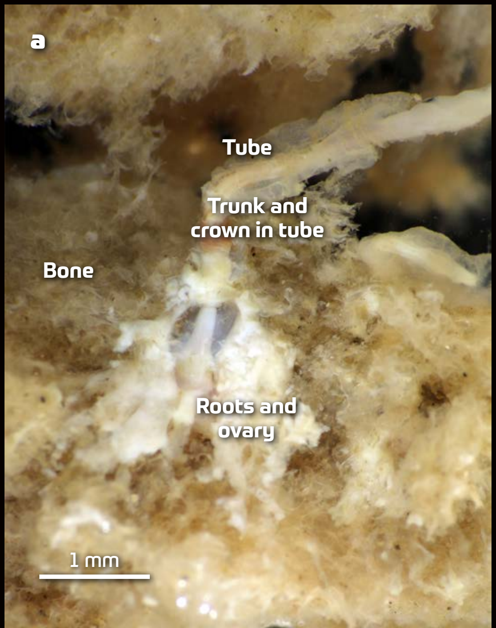


FIGURE 3. (a) *Osedax* specimen partially dissected from the whale bone. The bone was placed in ethanol so most color has been lost. (b) *Osedax* specimen dissected from the bone. Most of the "roots" were detached in this case.

BRINGING THE OCEAN TO A REMOTE LEARNING WORLD

Innovating with Telepresence

By Samantha Wishnak, Megan Cook, Kelly Moran, Jonathan Fiely, Megan Lubetkin, Emily Ballard, Madison Dapcevich, and Allison Fundis

Building from a foundation of pioneering telepresence technology that connects global audiences to the deep sea, the OET Education & Outreach team continued to innovate during the COVID-19 pandemic by quickly adapting to changes in travel and teaching landscapes. During this period, our Nautilus Live streaming platform and education resources were critical in offering real-time access to shipboard and remote scientists and engineers participating in expeditions, as well as students, educators, and the general public who were following along from home.

As part of COVID-19 mitigation protocols, staffing during expeditions aboard E/V *Nautilus* was significantly reduced and, in a difficult decision, our signature education programs were postponed. Accepted participants for the 2020 Science Communication Fellowship, a program immersing formal and informal educators in the Nautilus Corps of Exploration as expedition communicators, and the Science & Engineering Internship Program, a program providing hands-on workforce development training and mentorship for community college students, undergraduates, and recent graduate STEM students, were deferred to the 2021 expedition season. Participants were encouraged to engage in exploration via telepresence and in other virtual opportunities throughout the year. Strengthened by over a decade of experience with virtually connecting learners all over the world to seagoing expeditions and explorers in real time, OET was uniquely positioned to lead impactful learning experiences during this period when remote learning and working became a necessity.

NEW WEBSITE LAUNCH

In early 2020, we successfully launched a completely refreshed NautilusLive.org that now provides extensive situational awareness and resources for a range of audiences, including scientists, students, educators, and the general public (Figure 1). This fully responsive website is designed for use on a range of devices

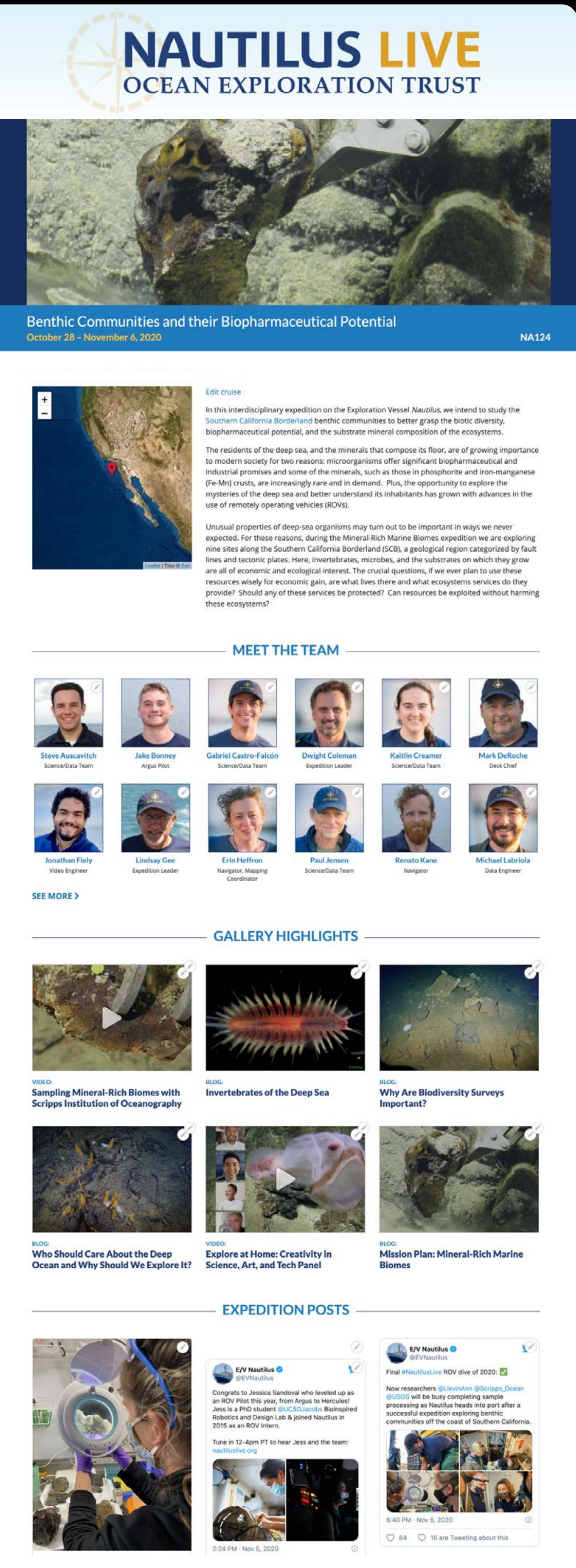


FIGURE 1. Development continues on the redesigned NautilusLive.org website as the central portal into OET expeditions for students, educators, scientists, and the general public who all remotely explore along with us.

and contains the latest expedition content, social media updates, and four live-streaming channels that offer real-time access to expedition operations.

With reduced shipboard staffing and our resulting expedition outreach paced more asynchronously, we optimized several features of the new website to support this new paradigm. Dedicated expedition pages serve as archives for all related team members and featured content, and a new Expedition posts section allows social media posts to be permanently linked in order to feature personal perspectives and storytelling from cruise participants both on ship and ashore. Expanding across seasons, a decade of *Nautilus* expeditions is now searchable by map location, year, region, and topic for more in-depth exploration. Highlighting our Education Resources page, an #InspiredByNautilusLive section highlights social media posts from members of our growing community and their use of our lessons, programs, and live streams in their learning spaces at home, at school, and in the community.

As many expedition participants and Scientists Ashore engaged remotely from home offices, several features of our website were further developed to support partners exploring with us via telepresence. The "on watch" website roster expanded to feature all shoreside participants along with at-sea watchstanders to improve situational awareness for viewers. A new Data Management page provided information for the public and researchers to efficiently access our data and samples through publicly available repositories or OET request forms. As science teams require access to additional resources to successfully conduct dives from shore, we plan to build out our Scientists Ashore portal to streamline remote operations.

EXPEDITION OUTREACH AND ONLINE VIEWERSHIP

Expedition outreach this season was designed to operate from shore, independent from at-sea operations—a departure from our signature outreach model offering audiences the immersive experience of interacting with the team members in ship spaces at sea. Without Science Communication Fellows, Communications Leads, or Documentarians aboard *Nautilus*, the pace of our expedition outreach became more asynchronous, with most web and social media content facilitated and created by team members off ship. Due to staffing limitations, our 24/7 live streams could not support round-the-clock moderating of viewer comments and questions. Instead, we used pre-scheduled special Q&A sessions facilitated by shoreside staff and partners.

Despite these changes, we observed higher levels of viewership and engagement across our live stream and social media platforms this season. The Nautilus Live YouTube channel received over 20 million views of the live streams and channel-wide highlight videos, with the same level of live stream minutes watched in just three months as compared to our entire 2019 expedition season, which was nearly twice as long. Similarly, engagement levels with our content across Facebook, Instagram, and Twitter exceeded those of our 2019 season despite the shorter operating period. A highlight video comparing our 2020 and 2019 surveys of a decomposing whale fall at Davidson Seamount within Monterey Bay National Marine Sanctuary captured the attention of the public with over 2 million views across our platforms (Figure 2).

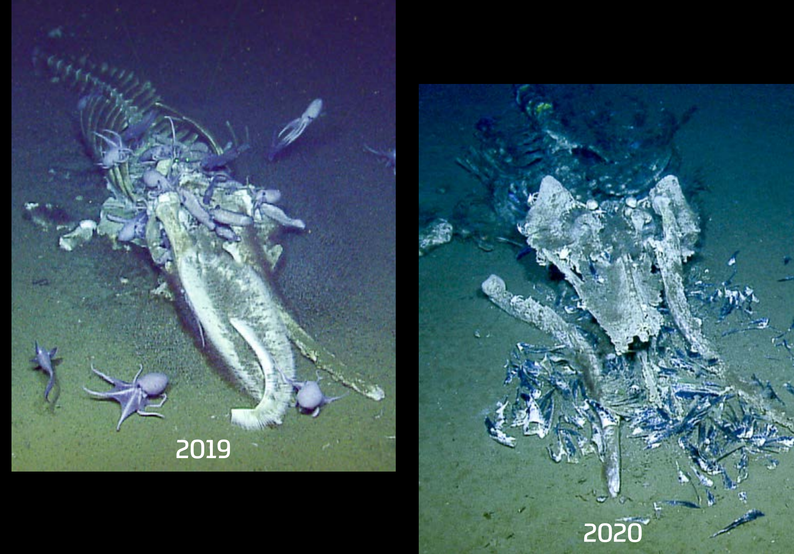


FIGURE 2. The top social media highlight of this year's expedition compared the noticeable decomposition of a whale fall surveyed in 2019 and 2020 at Davidson Seamount.

Our increased viewership levels and the appreciative comments we received from viewers on our social media platforms reflected pandemic policies that kept people around the world at home and connected through various devices. Viewer comments ranged from education settings, with a college professor writing in, "We viewed the live-stream during class today to highlight the national marine sanctuaries off the California coast," to home quarantines with a viewer sharing, "Just wanted to tell you that watching *Nautilus* videos has been added to my self-care routine."

Shipboard quarantine restrictions prevented press events while in port, but ongoing research involving data collected aboard *Nautilus* continued to be featured in online news publications, including Scripps Institution of Oceanography research coverage in *Wired* (Niiler, 2020), Charles Darwin Foundation's announcement of 30+ new species discovered in the Galápagos Islands (Grijalva, 2020), and Hakai Magazine's feature on seamounts of British Columbia (Lavoie, 2020). Since spring 2020, we have also seen a jump in footage requests from online media outlets, as well as from documentary productions for Smithsonian Channel, BBC Natural History Unit, and other national and international media production companies.

REACHING LEARNERS LIVE AND ASYNCHRONOUSLY

Recognizing the need for synchronous and asynchronous instruction support for educators teaching in a new format, OET designed three new virtual learning events series this season (https://nautiluslive.org/education/events): Meet the Team, featuring students and young professionals; Next on *Nautilus*, previewing expeditions; and Explore @ Home, tackling a deep-sea STEM subject. Using telepresence, and produced in partnership with the University of Rhode Island's Inner Space Center, 17 weekly events connected learners at home or in school with exciting live events, diving into various topics, discoveries, technologies, and careers in ocean exploration (Figure 3). Programs introduced learners to professionals from the Corps of Exploration, focusing particularly on Black, Indigenous, and People of Color (BIPOC) students and collaborators to highlight these professionals for our global audience. Broadcast over social media, the series reached audiences with more than 145,000 views between September and December. Members of the Corps of Exploration also continued their work as career role models by giving guest presentations for students across the country and around the world. We look forward to continuing approachable and engaging opportunities for students to meet STEAM professionals through the season ahead, including a return of our ship-to-shore live interactions from the studio aboard E/V *Nautilus*.

OET was also able to support many other organizations who pivoted to virtual events in their programming responses including the NOAA Office of National Marine Sanctuaries, AltaSea, NASA Jet Propulsion Lab, NASA TV, and university partners like Tuskegee University.

EDUCATION RESOURCE DEVELOPMENT FOR AT-HOME LEARNING

OET offers a suite of over 100 educational resources designed to link classroom STEM content and twenty-first century skills with real-world applications of concepts fundamental to deep-sea exploration (https://nautiluslive.org/education/resources). OET has a collection of inquiry-driven STEM Learning Modules aligned with and guided by the performance expectations of the Next Generations Science Standards, Common Core State Standards, and Ocean Literacy Principles. Expanding this year, new resource development focused on easily set up, engaging activities suitable for the at-home learning environment without a heavy reliance on high-bandwidth streaming. New resources added to the collection include a silicate geology lesson (https://nautiluslive.org/resource/ocean-silicate-geology), a middle grades activity book (https://nautiluslive.org/resource/nautilus-activity-book), a deep-sea poetry book authored by a Corps of Exploration pilot, illustrated exploration vocabulary flashcards (Figure 4), and new animated videos (https://nautiluslive.org/video/2020/12/09/beyond-wow-six-types-ship-motion). All education resources are integrated within the redesigned Nautilus Live website, allowing for cross-promotion of related content and resources on all pages and fewer barriers to discovering new content.

To expand the accessibility of our content and prioritize culturally relevant learning experiences, OET also invested in caption and translation of our most popular discovery highlights, education videos, and the STEM Career profile video series. Spanish translations of all of OET's STEM Learning Modules will be available online at the start of

FIGURE 3. The live event series provided opportunities to join explorers and STEAM (science, technology, engineering, arts, and mathematics) professionals in conversations ranging from career mentorship to recent discoveries.

2021. Collaborating with the National Marine Sanctuary Foundation, NOAA Office of Ocean Exploration and Research, and Schmidt Ocean Institute on a new online portal for launch in 2021, we will continue to connect educators with modern teaching resources to bring the deep sea to life for learners.

COLLABORATIONS AND FUTURE DIRECTIONS

Across our education programs and entire organization, OET joined this year's national reckoning of racial injustice and committed to deeper change to combat racism and bias in STEM education and ocean exploration. We commit to making choices that reflect our dedication to anti-racism with the programs we run, resources we allocate, and messages we send. With this moment to reflect on our practices and programs as a staff, we commit to include, amplify, and make space for more BIPOC voices in the deep sea and STEM communities. We commit to do more to diversify our team, staff, trustees, and programs both aboard E/V *Nautilus* and behind the scenes, allowing this significant moment of national awakening to systemic and pervasive injustice to change us. It will both change us and lead us to work for positive change in our role within the deep-sea research and exploration community. Growth is continual, and OET has committed to do better and be bolder in encouraging our community to do the same.

OET launched a new initiative to envision and develop unique ways for people to encounter the ocean through transdisciplinary programming. This initiative strives to foster emergent ocean literacy, collaborative practice, and deep engagement. OET will continue to push the boundaries of education, outreach, and technological innovation through transformative collaborations that bring together different perspectives for a shared purpose.

OET looks forward to 2021, the thirteenth year of the Nautilus Exploration Program. We are eager to combine the best innovations from 2020 with our history of successful programs to bring the excitement of discovery and the inspiration of STEM-focused careers to global audiences. We are excited to share more technology storytelling as collaborations within NOAA's Ocean Exploration Cooperative Institute test innovative new tools in coordinated operations. As *Nautilus* returns to the Central Pacific, we enter the home of Native Hawaiian and Pacific Islander communities eager to provide opportunities to amplify traditional knowledge and share new encounters from the deep sea.

FIGURE 4. One of OET's 120+ STEM educational resources, the Exploration A-to-Z Flashcards introduce learners to creatures, features, and technology from the deep sea. Follow the QR code on each card to dive deeper into that topic with a *Nautilus* exploration highlight or image gallery. See https://nautiluslive.org/resource/exploration-az-flashcards.

NAUTILUS FIELD SEASON OVERVIEW

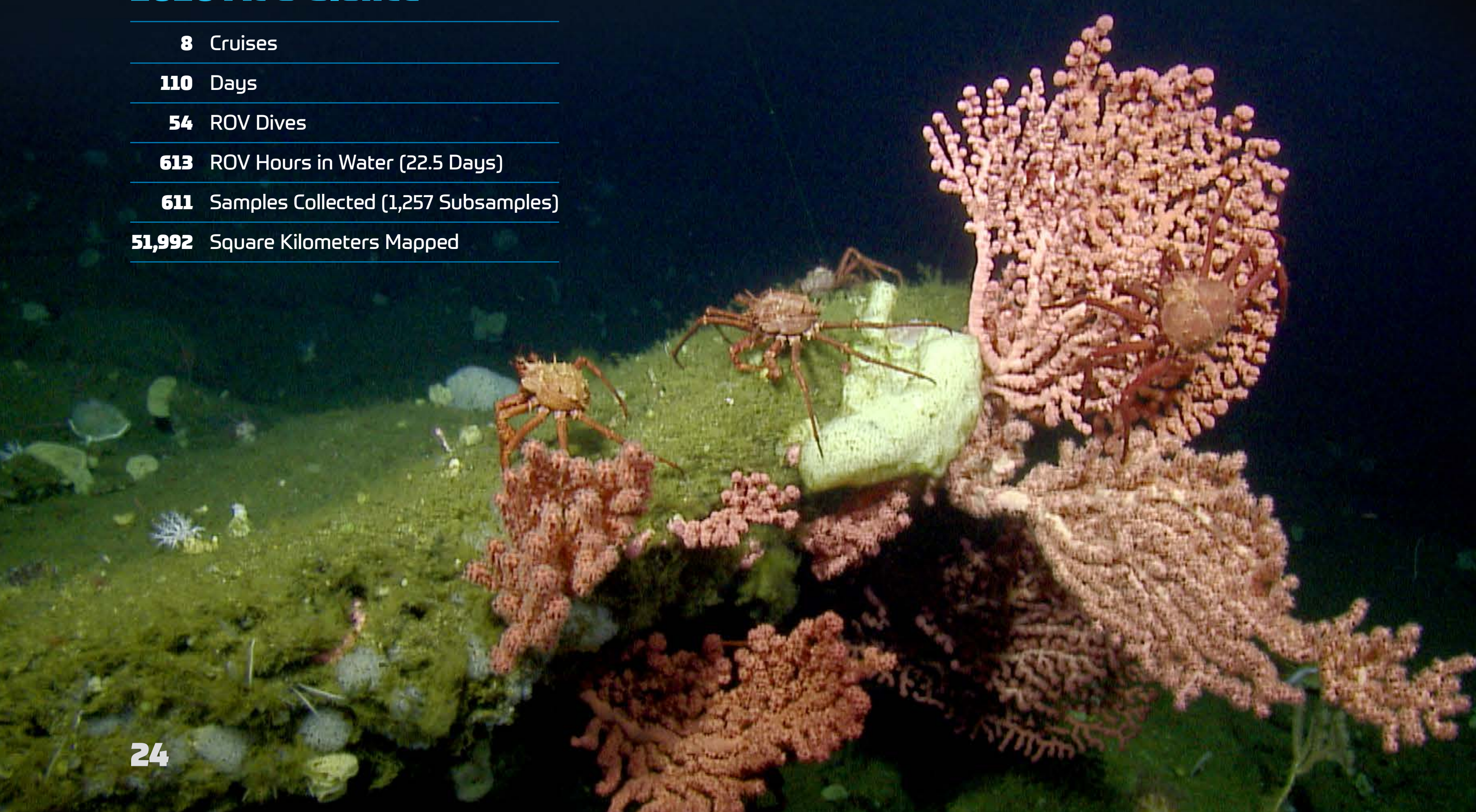
By Nicole A. Raineault

The 2020 E/V *Nautilus* field season was a triumph in a year full of adversity and immense challenges. We prevailed in commissioning a new engine, completing the design and installation of a new three-van mobile ROV command and control room and studio, and mounting a 3.5-month field season amidst a global pandemic. Grit, teamwork, and trust among all involved in these efforts led to great success. The Ocean Exploration Trust and its Corps of Explorers came together to conduct an unconventional, but productive, expedition season that will alter the way we explore and conduct outreach in the future. Eight expeditions occurred between mid-August and early December. A total of 54 ROV dives on six expeditions resulted in over 25 days of underwater video and oceanographic data. Beyond these statistics, the small team of 60 participants on board the ship throughout the season deserve special recognition for their dedication and hard work—they often put in longer hours and served in unaccustomed capacities to accomplish our goals. In fact, the small science management team aboard the vessel skillfully preserved many new types of samples for researchers this year (pages 18–19). This >65% reduction in at-sea participants unfortunately meant no interns and educators and many fewer scientists could sail. Thus, equally important and deserving of praise are the scientists and researchers who gamely accepted the challenge of leading dives from shore using unfamiliar technologies and protocols. Compared with 2019, the Scientist Ashore community was 45% larger in 2020 and much more actively engaged. Telepresence tools, some developed in past years and some tested at sea this year, transformed people's homes into remote ROV command centers (pages 26–27). Read on for some of the science and exploration highlights from these expeditions and explore further the articles summarizing some of the telepresence innovations and pivots to education and outreach programs (pages 20–23) that have propelled us forward this year.

The first exploration expedition of the season mapped the seafloor between San Pedro, California, and Sidney, British Columbia. *Nautilus* mapped the continental shelf break to image the deformation front during this expedition and on the subsequent Central California National Marine Sanctuary expedition to help researchers at the US Geological Survey better understand the morphology of the seafloor and potential hazards associated with this subduction zone.

2020 At a Glance

8	Cruises
110	Days
54	ROV Dives
613	ROV Hours in Water (22.5 Days)
611	Samples Collected (1,257 Subsamples)
51,992	Square Kilometers Mapped



The Ocean Exploration Trust partnered with Ocean Networks Canada and the University of Victoria for the fifth time in six years. This expedition met all objectives for both cabled observatory maintenance and scientific sample collection and exploration (pages 30–31).

Nautilus then turned south for three consecutive expeditions within US West Coast national marine sanctuaries. Although scientific leadership was different for each of the expeditions, they worked with a common specimen request list, wider teams of scientific experts, and many of the same goals of seafloor characterization, particularly for coral and sponge habitat. The first expedition combined habitat characterization and methane seep research at two Washington State canyons (Quinault and Greys; pages 32–33). Research coordinator Jenny Waddell led a team of onshore scientists to explore a range of substrate types in the deepwater portions of the canyon systems within or adjacent to the Olympic Coast National Marine Sanctuary. Andrew Thurber and two graduate students from Oregon State University sailed aboard to collect and process sediment cores and other seep fauna and operate a new deep-sea still camera, which captured high-resolution images of the seafloor on all subsequent dives in the 2020 season. The Oregon State University team seeks to better understand how methane seeps may fit into the ocean's blue economy by exploring the potential for material resources and biopharmaceutical and biotechnological compounds as well as the role of seeps in supporting commercial fish stocks and other organisms.

Experts from Greater Farallones National Marine Sanctuary and Monterey Bay National Marine Sanctuary, along with many others from NOAA's National Marine Fisheries Service, California Academy of Sciences, US Geological Survey, and academic research laboratories led dives exploring in and around Pioneer Canyon and adjacent to Davidson Seamount (pages 34–35). Samples were collected to help researchers better understand important ocean issues such as acidification and microplastic pollution and to enhance typical deep-sea census-focused and eDNA collections. Poor weather in the Monterey Bay area during this expedition forced us to work within the Channel Islands region for several days, but the flexibility and collaborative spirit among the research teams allowed us to easily transition to these dive sites.

On the subsequent Channel Islands National Marine Sanctuary and Santa Lucia Bank expedition, we were able to recover one dive in Monterey Bay National Marine Sanctuary to explore a new area on the southwest side of Davidson Seamount. Dives at Santa Lucia Bank explored new territory that is the proposed site for the Chumash Heritage National Marine Sanctuary and that also encompasses known spawning grounds for the commercially important petrale sole (pages 36–37). The remaining dives were spent around the Channel Islands, ground truthing substrate and habitat prediction models.

The final 2020 ROV expedition involved an at-sea team from Scripps Institution of Oceanography and the US Geological Survey to explore ridges and seamounts in the Southern California Borderland with a goal of gaining an understanding of the association between marine minerals, including iron-manganese crusts and phosphorites, and deep-sea fauna (pages 38–39).

Finally, a small team aboard *Nautilus* completed three weeks of seafloor mapping in the outer southern California US Exclusive Economic Zone to fill large gaps in seafloor bathymetry (pages 29–30). These new data help complete the 24% of the US West Coast Exclusive Economic Zone that had been unmapped and contribute important new data to the Seabed 2030 initiative whose goal is to have a complete bathymetric map of the seafloor in less than a decade.

In the winter of 2021, *Nautilus* will undergo a final phase of major upgrades, including lengthening the ship several meters to accommodate the DriX autonomous surface vessel, a new Ocean Exploration Cooperative Institute mapping system. DriX, along with other robotic assets, will be deployed from *Nautilus* during the 2021 field season. We plan to return to Lake Huron to continue seafloor mapping and target identification with ROVs in partnership with the Thunder Bay National Marine Sanctuary. The 2021 E/V *Nautilus* field season will begin in July and work along the west coast of the US to Canada before crossing the Pacific to devote the remainder of the field season to exploration of the Papahānaumokuākea Marine National Monument and waters around northwestern Hawai'i.

Telepresence Closes the Distance in E/V *Nautilus* 2020 Field Season

By Nicole A. Raineault, Zara Mirmalek, and Allison Fundis

Despite the global COVID-19 pandemic, the Ocean Exploration Trust successfully conducted a 2020 field season of nearly four months at sea. This year, the tenet of "safety first" required changes, including reducing the number of people on ship to maximize social distancing to the extent possible and adding a mask requirement (Figure 1). However, given OET's 12-year history of use and development of telepresence for E/V *Nautilus*, this did not require reducing the number of scientists conducting research. Over 50 dives, in locations from southern California to British Columbia, were conducted by expedition teams, some of whom were located on ship and some of whom were directing ROV dives from on shore across North America. *Nautilus* typically carries 48 people, including a science party of six to ten, three collegiate-level interns, and three educators in addition to the operations team. To reduce the risk of introducing COVID-19 to a vulnerable shipboard environment, some participants remained ashore for each of the eight expeditions, including most science team members and all interns and educators. This reduced the 2020 shipboard teams to 50%–70% capacity. In spite of the limitations to team size, all exploration goals, including new sampling requests, were met in 2020, and OET was able to uphold the well-known E/V *Nautilus* outreach program.

FIGURE 1. Shipboard participants followed additional safety protocols, including wearing masks.

The 2020 field season met and exceeded expectations: an expanded shoreside research team engaged in each expedition, additional new sampling objectives were met, the 24/7 live stream gained more views than in longer field seasons in the past, and a popular series of live virtual events showcased the diversity of talent involved in ocean exploration. With OET's development and use of telepresence infrastructure, there was reason to be assured that remote participation would be well supported (e.g., Matthew, 1981; Wojtas 2009; Coleman et al., 2014; Bell et al., 2015; Pallant et al., 2016; Stephens et al., 2016; Raineault et al., 2018; Lim et al., 2019, 2020; Miller et al., 2019). Pandemic conditions, however, not only increased the number of science team members preparing and participating from on shore but also required onshore participants to maintain physical separation from one another.

This year, 54 ROV dives were conducted with live streaming of subsea video to shore, where researchers viewed the video and graphical displays of oceanographic data. Watch leads, all of whom were remote from one another, maintained ongoing communications and shared observations that were logged in a text-based chat software, while one to two participants orally led the dives from home (Figure 2). The dive leads' voices were broadcast to the public-facing Nautiluslive.org website as well as to shipboard watch standers, producing a single conversation among the team, regardless of location. Periodically, an outreach specialist would participate orally from shore to host live Q&A with the watch-standing team. Feedback from the public and the scientific community was overwhelmingly supportive of the effort.

Given the unprecedented geographical dispersion of key onshore personnel, OET found that the ways in which adjustments to preparations for expeditions, ROV dives, and outreach were made were paramount to the success of the field program. These preparations included organizing more robust pre-dive planning, communications, and science tools, as well as implementing new procedures to complement existing telepresence tools and overcoming challenges posed by the physical separation among team members (Raineault and Fundis, 2020). Unable to view data in a shared environment, normatively simple tasks such as reviewing new seafloor maps to plan an ROV dive traverse became complex as the number of reference screens

FIGURE 2. National Marine Sanctuary science leads employed at-home telepresence setups from which to direct dives. In addition to an Internet connection, key elements included multiple monitors to view the dive, science chat, and oceanographic data graphs, and a headset for communication. *Image credit: Jennifer Brown*

increased and face-to-face interaction decreased. Daily phone calls between dive and shipboard leads were critical to ensuring a common understanding of the goals and intent of the dive and expedition plans. With the addition of increased interpretation support, dive plans were modified (pre-cruise) to include situational awareness information for science objectives, sampling, and navigation. Also, ROV and mapping navigators were tasked with providing constant updates of at-sea conditions and operational limitations to the teams ashore, as the scientists leading dives remained in need of important local environmental cues such as intensifying winds or building seas that can push the ship to the edge of its operational window.

One of the biggest challenges, common in the adoption of any new technology, was a matter of resolving varied technical difficulties specific to each watch lead, their experience, and their local (at-home) setups. For some, it was the first opportunity to utilize telepresence for their data collection. For all, over 30 individuals, oral communication with one another onshore and with watch standers on board was supported using new software. Audio quality and connectivity issues were difficult to assess and appeared to vary by individual incidence. Issues that would normally be an inconvenience to a shoreside scientist could present a roadblock to being a dive leader if unresolved in a timely manner. Fewer staff on the ship created additional workloads for the teams, but the matter was overcome by having dual watch leads and ongoing communication stability provided by text via the Science Chat.

Both on ship and on shore, the pandemic necessitated a reduction in co-located participants on an unprecedented scale, even for OET. Fortunately, the ongoing development of telepresence with NOAA and OET had only one year earlier resulted in reaching a milestone: the conduct of a two-week expedition for which the chief scientists were all required to participate from shore and supported by the use of experimental communication protocols (Lim et al., 2020). Preparations to keep the 2020 season going included furthering the adoption of new technologies, accounting for increasing requests for sample collection, and accommodating expanded onshore participation. Building support for growing inclusivity and opportunities for broader participation will continue in the future, regardless of pandemic restrictions.

Expanding Seabed Mapping

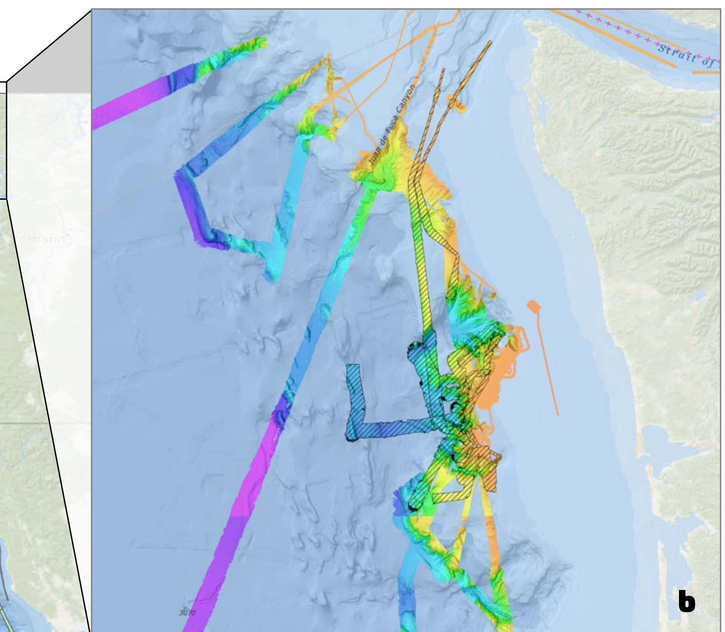
Supporting the US National Ocean Exploration and Characterization Efforts in the US West Coast Exclusive Economic Zone

By Lindsay Gee, Erin Heffron, Renato Kane, Vicki Ferrini, and Nicole A. Raineault

Seafloor mapping remained an important endeavor during the *E/V Nautilus* 2020 season. Mapping provides information about seafloor features, sediment coverage, and methane gas seepage, allowing us to choose targets and optimize dive tracks for exploration as well as to safely navigate the ROVs in steep areas of canyons along the continental margin. The final expedition of 2020 filled gaps in the bathymetry off Southern California in support of the *National Strategy for Ocean Mapping, Exploring, and Characterizing the US Exclusive Economic Zone* (NOMEC, 2020). *Nautilus* teams mapped a total area of nearly 52,000 km^2 of seafloor along 13,445 km of trackline during the season (Figure 1).

Mapping commenced in a section of the Ocean Networks Canada offshore network (pages 30–31). The goal was to create a high-resolution bathymetric map of an unexplored vent field. The data provided crucial information for planning and ROV navigation for an upcoming 2021 survey and sampling program to be conducted by a team of Memorial University of Newfoundland researchers.

The next expeditions mapped areas of Washington and Oregon coastal waters in the vicinity of Olympic Coast National Marine Sanctuary (OCNMS), as well as the Cascadia margin deformation front in support of the EXpanding Pacific Research and Exploration of Submerged Systems (EXPRESS) initiative. NA121 mapping efforts primarily supported ROV dives, which on this expedition were split between NOAA OCNMS exploration and methane seep dives led by Oregon State University (OSU) (pages 32–33). Poor weather prevented ROV dives on several days, which allowed us to map gaps in bathymetry and to fully map two essential fish habitats that were a high priority for OCNMS. Prior to OSU-planned dives, locations with reported seeps were resurveyed, often on the way to the site to confirm seep activity and location. The water column backscatter data were immediately processed and the dive plan altered as necessary to investigate areas with anomalies that suggested active gas seeps.



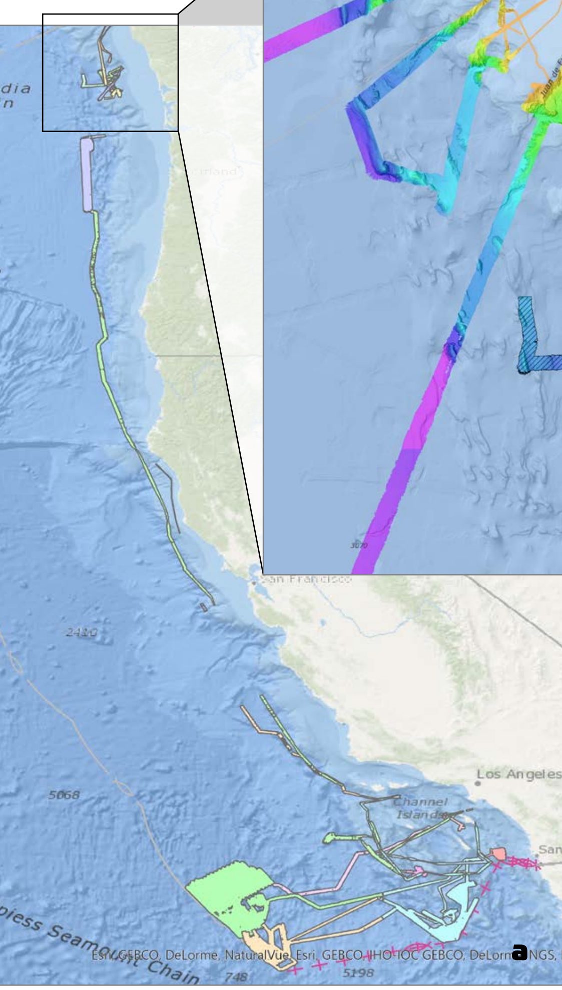


FIGURE 1. (a) Overview of E/V *Nautilus* mapping coverage in the US EEZ off the US West Coast during exploration cruises in 2020. Each survey is represented by a differently colored polygon. (b) Image of E/V *Nautilus* mapping completed off the coast of Washington in the vicinity of the Olympic Coast National Marine Sanctuary from 2015 to 2020. The hashed areas show mapping completed in 2020.

Mapping activity aboard *Nautilus* continued to fill gaps in bathymetry and backscatter needed to support dives on Santa Lucia Bank. Further south, this work finalized mapping of the California Borderland to support targeted and safe exploration of the region by ROV during NA124 (pages 38–39). Mapping commenced on NA122 and continued on NA124. OET COVID-19 mitigation policies restricted the overall number of people on board, resulting in a reduced operations team when larger science parties were required. During NA124, the reduced team resulted in shorter (eight-hour) ROV dives, which in turn allowed the ship to complete mapping for each dive site over night. The mapping of dive locations was

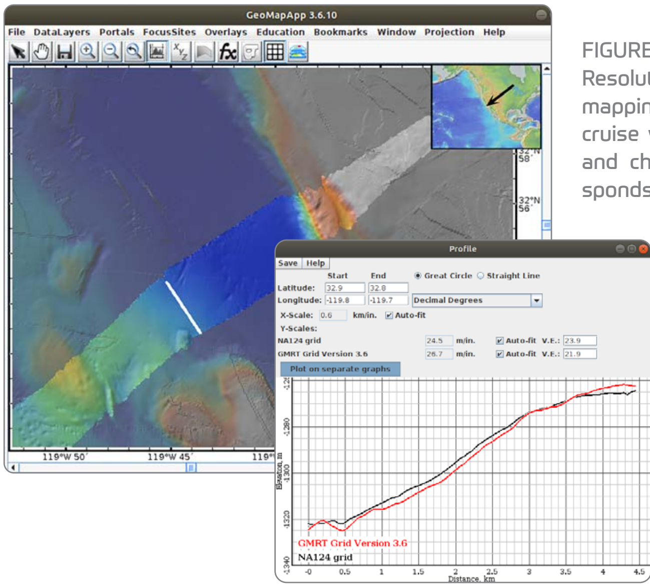


FIGURE 2. The image shows the use of Global Multi-Resolution Topography (GMRT) QA/QC tools for NA125 mapping. The new GMRT tiles generated during the cruise were compared to the current GMRT data set and checked for consistency. The white line corresponds to the profile image.

combined with filling further bathymetry gaps on transits across the Borderland between sites.

The final expedition of the season, NA125, was a mapping-only cruise that targeted gaps in NOAA's US bathymetry coverage and gap analysis (https://iocm.noaa.gov/seabed-2030-bathymetry.html) within the US Exclusive Economic Zone (EEZ). The primary mapping area was along the western boundary of the EEZ west of San Diego. A secondary mapping area located in the more protected regions in the California Borderland was completed when weather conditions in the primary area were unsuitable. All of the mapping was conducted with both multibeam sonar and sub-bottom profiler systems. OET worked closely with partners to ensure the data were processed on board by the end of every cruise and made available to those producing the global seabed models. The mapping of gaps also aligns with broader international goals. OET contributed directly to the Nippon Foundation–GEBCO Seabed 2030 project by submitting the products directly to the project, in addition to making the data publicly available in the NOAA National Centers for Environmental Information (NCEI) archives.

Over the last few years, *Nautilus* mapping data have also been contributed directly to the Global Multi-Resolution Topography (GMRT) Synthesis. OET has worked with the GMRT team to improve workflows for processing and integration into GMRT, as well as to smooth the path for submission of data to the Seabed 2030 Regional Centers (Figure 2). In 2020, data collected on 28 *Nautilus* cruises from 2015 to 2019 were prepared for integration into GMRT, revealing some minor issues that were addressed prior to submission to NCEI. Combined, the submitted data cover more than 300,000 km^2 of seafloor in the Pacific Ocean.

In order to accelerate the rate of data integration, not burden the GMRT team, leverage the skills of the *Nautilus* onboard mapping team, and contribute to the mapping community, GMRT tiling tools were adapted for use aboard *Nautilus* (Ferrini et al., 2020). OET prototyped the use of the tools on board in 2019, and in 2020, GMRT tiling tools were integrated into the standard operating procedures. These tools improve the data submission workflow and provide a testbed for tools that can benefit the broader seabed mapping community.

Since *Nautilus* exploration began in the area in 2015, OET has conducted over 20 cruises and nearly 140 ROV dives in this region, with the majority including some seabed mapping. The compiled map of the areas south of Point Conception and the mapping on NA125 (33,400 km^2) more than doubled the total area (over 63,000 km^2) mapped by *Nautilus* in the US EEZ (Figure 3). This mapping has provided modern, high-resolution bathymetry, backscatter, and sub-bottom data and processed products, as well as multibeam water column data, that are publicly available to all. These data have been used to locate numerous gas seeps in the region, in addition to directly supporting the exploration ROV dives.

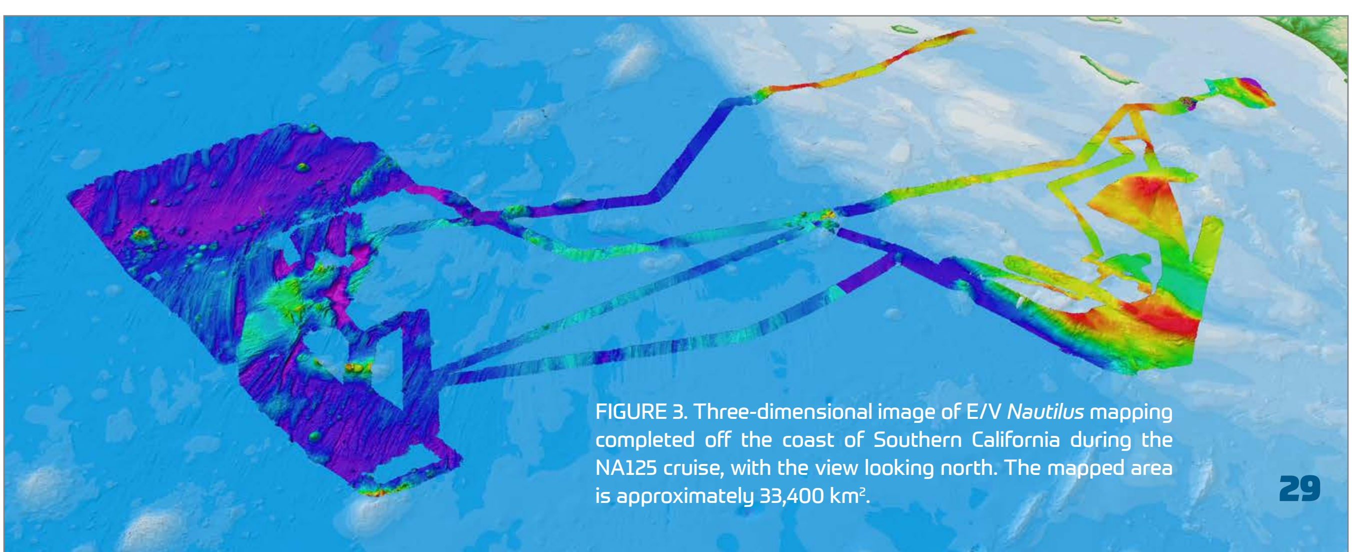


FIGURE 3. Three-dimensional image of E/V *Nautilus* mapping completed off the coast of Southern California during the NA125 cruise, with the view looking north. The mapped area is approximately 33,400 km^2.

Ocean Networks Canada

Advancing Ocean Observing Technology and Science

By Ian Kulin, Allison Fundis, Meghan Paulson, Sheryl Murdock, Steve Mihaly, Fabio C. De Leo, Andrew Baron, Nicolai Bailly, and Leslie Elliott

Marking the fifth anniversary of working in partnership with Ocean Exploration Trust, the E/V *Nautilus* team supported the maintenance of the University of Victoria's Ocean Networks Canada (ONC) offshore cabled ocean observing infrastructure (Figure 1). Despite the global pandemic—which limited the number of onboard crew and required strict adherence to COVID-19 safety protocols—the team was able to successfully maintain, upgrade, and expand over two dozen instruments in 2020.

During the 14-day expedition from September 4 to September 18, 2020, and in coordination with researchers from around the world, *Nautilus* visited 11 sites to deploy, recover, and maintain sensors and instruments, more experiments than ever before in a single expedition. The team completed a significant amount of scientific work using the ship's ROV *Hercules,* performing numerous vertical and horizontal video surveys, mapping the seafloor, and collecting biological and geological samples.

ROV *Hercules* placed a total of 18 new passive larval tube traps on the ocean floor at all of ONC's deepwater sites (Figure 2). Once in place, these tubes will collect larvae of benthic organisms over one full year to better understand patterns of connectivity, dispersal, and biodiversity of deep-sea animals. This new research is a collaboration between researchers from the United States, Spain, France, Portugal, United Kingdom, Japan, and Canada, including ONC.

Using the ROV *Hercules* "slurp" suction sampler at the Endeavour Hydrothermal Vent Field Marine Protected Area, the science team gathered samples of a new-to-science sponge species. These specimens are being studied by researchers at the Natural History Museum of London to further examine microbial symbionts living within the sponges as a way to understand what they eat. Additionally, a sample of this new species will be deposited in the zoological collection of the Royal BC Museum, Victoria.

The growing field of environmental DNA, or eDNA, research is a paradigm shift in ocean science, making it possible to monitor ecosystem biodiversity with only a few liters of seawater. Deployed at Endeavour in 2019 and recovered by *Nautilus* in 2020, paired McLane instruments collected samples for eDNA and associated water chemistry to enable time-series analysis of temporal changes in the microbial biodiversity in hydrothermal vent fluids (Figure 3). Microbial colonization modules attached to the McLane sampling apparatus deployed in the vents' hydrothermal fluids will be used specifically to study protists—slightly more complex microbes with unknown roles

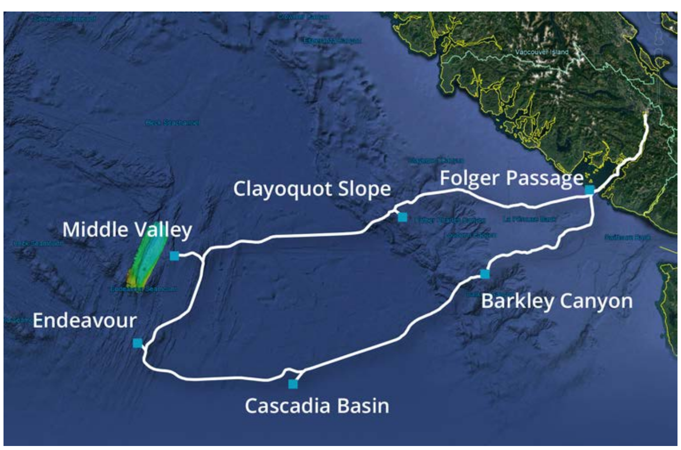
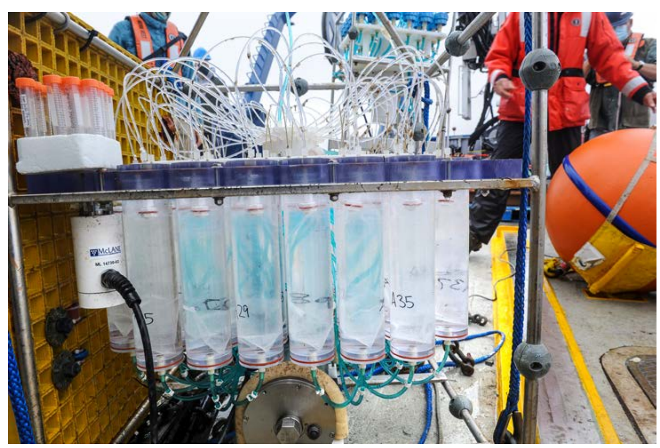


FIGURE 1 (above). Ocean Networks Canada cabled infrastructure and new multibeam map near Middle Valley.

FIGURE 3 (below). The eDNA sampling device with phytoplankton sampler. *Image credit: ONC*



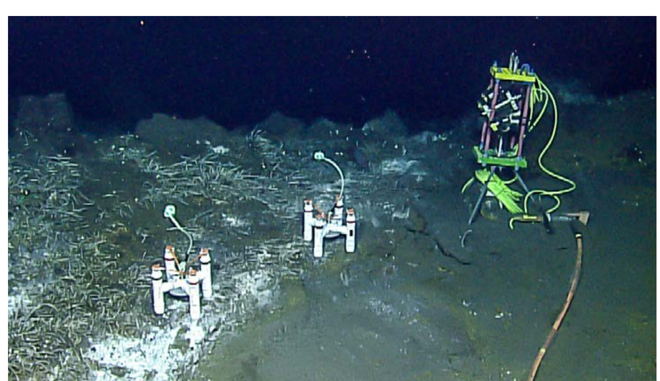
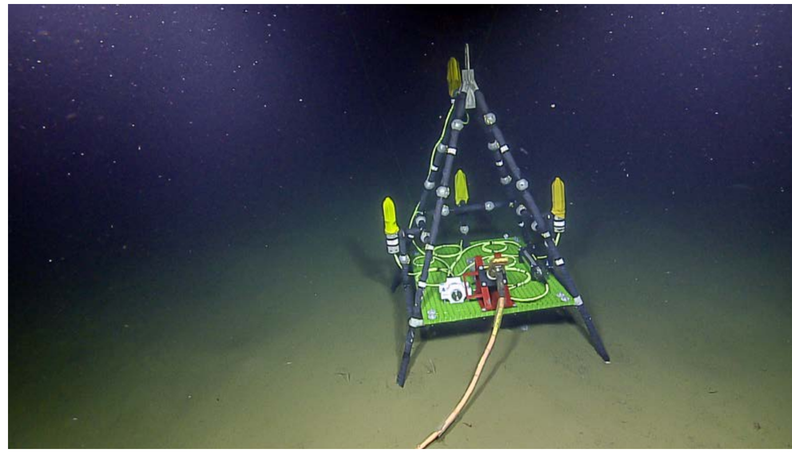


FIGURE 2 (right). Larval traps deployed at Endeavour Hydrothermal Vent Field Marine Protected Area. *Image credit: OET/ONC*

FIGURE 4 (left). Deploying cable to connect tsunami array at Cascadia Basin. *Image credit: ONC*

FIGURE 5 (below). New hydrophone at Cascadia Basin. *Image credit: OET/ONC*



in hydrothermal vent ecosystems. Scientist Sheryl Murdock will use eDNA from the sampler to compare organisms grown in culture from the colonizers to the time series of eDNA samples. Study of individual genomes and abundance shifts over time will increase understanding of the mechanisms of protist survival in these harsh vent environments.

ONC completed the highly anticipated tsunami detection array—first conceived and partially deployed in 2012—on the vast abyssal plain at Cascadia Basin, ONC's deepest site (Figure 4). The array was to have one instrument at the Cascade instrument platform and three others 120° apart and 25 km away from the instrument platform, but two of the three experimental 25 km fiber-optic cables were damaged during cable laying in 2012. Since then, ONC developed an innovative solution using the cables' copper conductors to transmit both power and communications, eliminating the need for fiber optics. This innovative "comms over copper" solution—deployed in 2016—allowed real-time data to flow from the bottom pressure recorders located at the ends of two of the long cables.

In September 2020, the third fiber-optic cable was laid using a custom cable-spooling frame lashed to the deck of *Nautilus*. The entire operation was conducted using the weight of the falling cable (instead of power) while the vessel moved slowly forward, a band brake on the spool to control its speed, and pre-calculated tables to ensure the cable lay speed matched the vessel speed.

Once the cable was laid on the seafloor, the final bottom pressure recorder package was dropped overboard with two floats for a freefall deployment. ROV *Hercules* then plugged the instrument into the Cascadia Basin junction box, connecting the bottom pressure recorder to the Internet-connected network. This third and final cable allowed the fourth instrument to switch from operating autonomously to providing real-time data.

Completing the tsunami array, which now consists of three triangulated bottom pressure recorders surrounding a fourth at their center, was a significant accomplishment. This array allows precise real-time determination of tsunami wave speed, direction, and amplitude. The ability to assimilate open-ocean data from ONC's cabled observatory into an operational tsunami forecast model makes it possible to mitigate the impact of future tsunamis approaching the west coast of British Columbia.

At Cascadia Basin, the team also installed a new hydrophone array (Figure 5) and made preparations for a second pathfinder neutrino experiment (installed later in 2020) and additional cable extension installations (to be installed in 2021).

During inclement weather that prevented ROV operations, the team undertook mapping operations using *Nautilus's* multibeam echosounder to create a high-resolution bathymetric map at West Valley, an unexplored vent field near the undeveloped Middle Valley branch of ONC's offshore network.

While at Barkley Canyon, preparations were made to reconnect this important site to the network. With depths ranging from 200 m to 2,000 m, this deep-sea study site provides a significant location for the study of gas hydrates, sediment dynamics, upwelling, plankton, and productivity. The team also recovered a corrosion experiment deployed in 2019 that was testing various metals and their ability to hold up under 100–200 atm of pressure—equivalent to ocean depths of 1,000–2,000 m.

Other expeditions in 2020—aboard the Canadian Coast Guard Ship *John P. Tully* using the Pelagic Research Services ROV *Odysseus*—resulted in retrieval of the Delta Dynamics Lab from the mouth of the Fraser River and installation of a new hydrophone at Folger Passage and a new hydrophone array in the Strait of Georgia, home to the resident endangered southern killer whales near Canada's busiest port, Vancouver. New community observatories were installed in Douglas Channel near Hartley Bay in partnership with the Gitga'at First Nation and in Alberni Inlet at China Creek with the Nuu-chah-nulth people.

Olympic Coast National Marine Sanctuary and Gradients of Blue Economic Seep Resources

By Andrew Thurber, Jenny Waddell, Kerry McPhail, Lila Ardor Bellucci, Meredith Everett, Abigail Powell, Erica Fruh, Marc Fries, Susie Cummings, Elizabeth Clarke, Katie Wrubel, Erin Heffron, and Nicole A. Raineault

The Cascadia margin, extending from Northern California to British Columbia, is incised by submarine canyons that connect the shallow waters to the deep sea. These canyons host abundant cold-water coral and sponge habitats and are the location of thousands of recently discovered methane seeps, which together form essential fish habitat that fuel coastal ecosystems and economies. Between September 19 and October 1, 2020, scientists from Oregon State University (supported by an award from NOAA OER) and Olympic Coast National Marine Sanctuary (OCNMS; supported by NOAA's West Coast Deep Sea Coral Initiative) teamed up to explore seafloor habitats off Washington state's Pacific coast. The two teams alternated leading ROV dives, opportunistically collected samples to facilitate the success of both projects, and co-led a final dive. Through this collaborative approach, the team was able to make the most of the time at sea despite an impressive autumn storm that rolled in from the Pacific Ocean. The 1,506 km^2 of new high-resolution seafloor mapping data collected during this cruise were augmented by 381 km^2 of data acquired during an earlier E/V *Nautilus* mapping transit.

SEEPS

Methane seeps are areas where the greenhouse gas methane leaks from subsurface reservoirs, providing a source of energy to the ocean. As it is released, methane is captured and modified through a variety of microbially mediated reactions, resulting in the creation of a unique habitat that adds to ocean biodiversity. We explored methane seeps to better understand how they may fit into the blue economy, the sustainable use of marine resources for economic growth. By looking for material resources and biopharmaceutical and biotechnological compounds, and elucidating the role of seeps in supporting commercial fish stocks and other organisms, we hope to better understand how seeps fit into the ocean ecosystem at large. This question is particularly relevant on the Cascadia margin where more than 2,000 seeps have been identified in the past decade, yet only a handful of them have been visited. During this voyage, we explored six active seepage sites ranging in depth from 180 m to 1,312 m. These vastly different sites included one seep with massive carbonate boulders and another with an impressive 60 m-wide microbial mat, both at 1,000 m depth (Figure 1). We sampled across two canyons, Quinault and Grays, collecting sediment cores, biological samples, and imagery at areas of active seepage and along transects leading away from them.

DEEP-SEA CORAL AND SPONGE HABITATS

Exploration of deep-sea coral and sponge habitats focused on areas both within and adjacent to OCNMS that have been protected since 2006 as essential fish habitat by the Pacific Fishery Management Council (Figure 2). These beautiful habitats showcase the remarkable biodiversity within OCNMS and in essential fish habitats of Quinault and Grays Canyons. OCNMS team members, who led dives from ashore at locations across the United States, thanks

METEORITE

In March 2018, a massive meteorite splashed into Olympic Coast National Marine Sanctuary near Quinault Canyon. With leadership from NASA's Marc Fries and his team, ROV *Hercules* excavated a pit in the seafloor that had previously yielded meteorite fragments. Using a variety of new tools and equipment, including an industrial switchable magnet and rare earth magnets attached to the exhaust pipe of a dredge, *Hercules* was able to collect samples that will be analyzed at the Johnson Space Center in Houston.

FIGURE 1. A very dense microbial mat named "the pancake" was sampled to explore for novel chemical compounds that may have societal use.

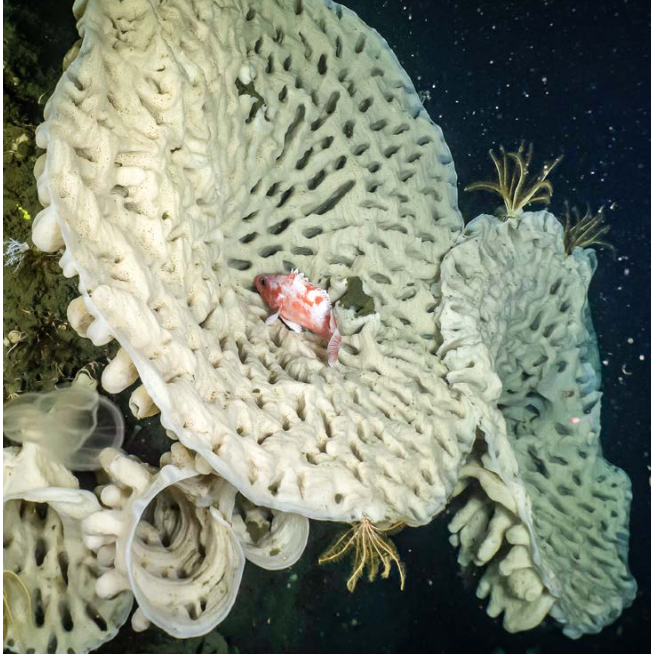


FIGURE 2. An aurora rockfish (*Sebastes aurora*) on a large *Heterochone calyx* sponge in Grays Canyon is an example of the common association between fish and sponge.

to OET's telepresence capabilities, provided expert interpretation for viewers as ROV *Hercules* revealed the fantastic forms taken by the region's corals and glass sponges. In a deep dive to 1,300 m within Quinault Canyon that traversed a prominent ridge in the "Biogenic 2" essential fish habitat area, ROV *Hercules* encountered old colonies of *Paragorgia* that had several axes of growth and featured some of the "floofiest" polyps of bubblegum coral ever encountered by expedition scientists. Deep-sea sponges were found to be especially diverse, and collections included several specimens that will help to validate new species records and potentially identify a band disease affecting a large *Heterochone calyx*.

COLLABORATION TO ADVANCE EXPLORATION

As the results of these dives attest, the deep sea offers a great diversity of habitats and communities (Figure 3). This was clear along a transect in Quinault Canyon where we encountered two seeps: a small area with just a few clams and a second active seepage area with tubeworms and clams adjacent to an amazing bubblegum coral garden. As the ROVs continued along the canyon wall, sponges and many other animals were observed. The final dive of the expedition was a jointly planned effort in which the ROVs traversed the northern wall of the Grays Canyon essential fish habitat and to an area of methane seepage. The steep canyon wall was covered in abundant sponges, including very large glass sponges. The ROV pilots captured imagery to create a three-dimensional photomosaic of a huge group of *H. calyx*, and a number of previously unidentified sponge species were collected. The top of the canyon featured many small seeps that were often marked by little more than a white microbial mat with methane slowly bubbling from the seafloor. This collaborative dive reinforced the co-occurrence of methane seep habitats with the great biological diversity present along the Cascadia margin, and this collaboration cruise provided a basis for more holistic appreciation of the distribution of heterogeneous habitats on the Cascadia margin.

We wish to acknowledge the support of the Quinault Indian Nation, especially Joe Schumacker, Marine Resources Scientist with the Quinault Indian Nation, one of four Coastal Treaty Tribes with reserved rights to marine resources within Usual and Accustomed (U&A) harvest areas on the Washington coast. Mapping and ROV dives occurred within the Quinault U&A and may support tribal resource management.

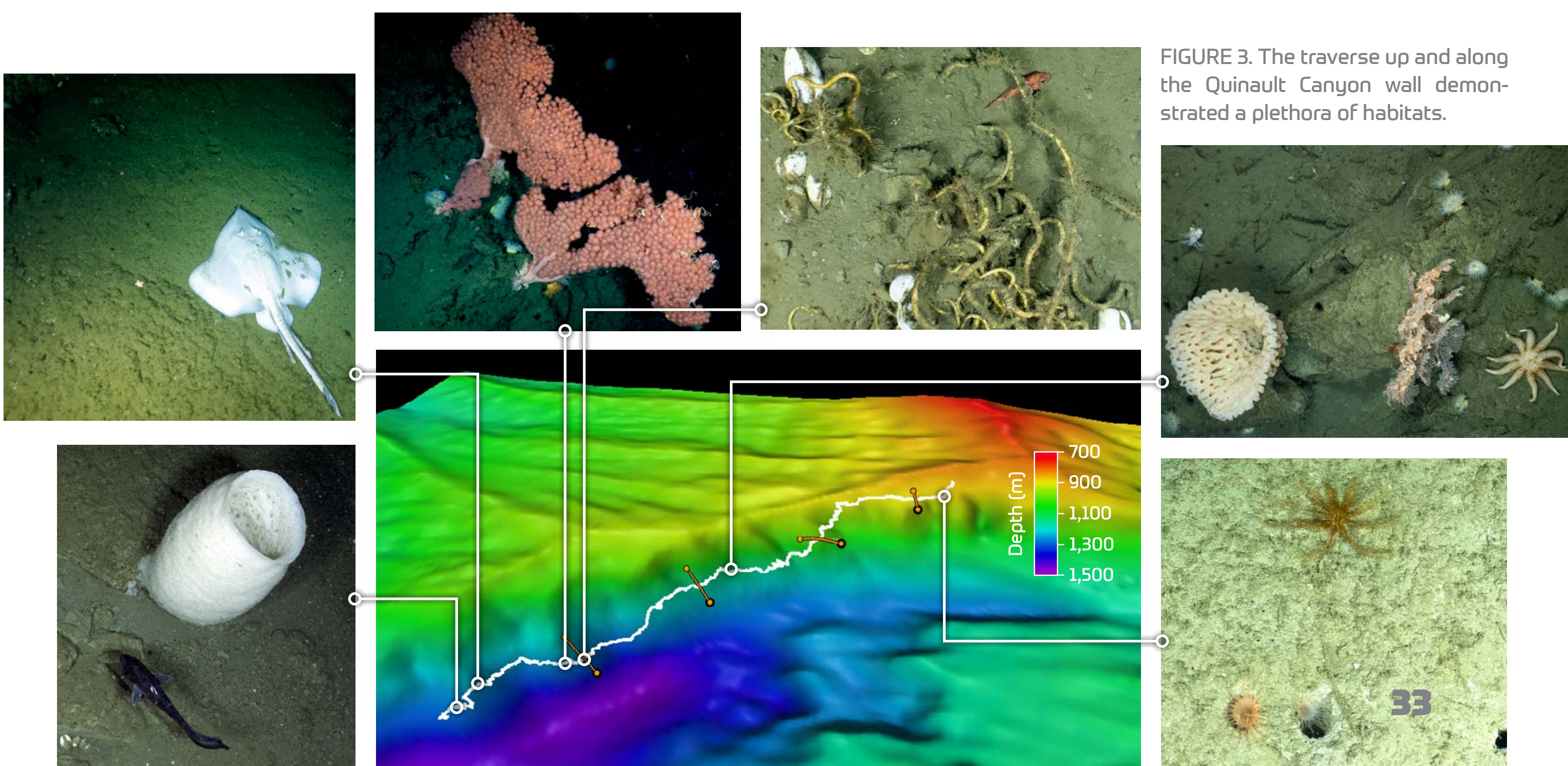


FIGURE 3. The traverse up and along the Quinault Canyon wall demonstrated a plethora of habitats.

Exploring Monterey Bay National Marine Sanctuary

By Chad King, Jan Roletto, Sage Tezak, Gary Williams, Jennifer Brown, Guy Cochrane, Erica Burton, Kirsten Lindquist, Amity Wood, and Justin Holl

Monterey Bay National Marine Sanctuary (MBNMS) encompasses 13,784 km^2, extending 444 km from Marin County in northern California to Cambria in San Luis Obispo County in central California. MBNMS is one of 14 US national marine sanctuaries and two marine national monuments managed by NOAA. National marine sanctuaries are areas of special national significance designated to provide for conservation, management, and enhanced public awareness of the ocean. Its centerpieces are Monterey Bay Canyon and two rarely explored regions, Pioneer Canyon and Davidson Seamount. The head of Pioneer Canyon is approximately 38 km west of Half Moon Bay. With depths over 1,300 m, this canyon was formed by the outflow of the Sacramento River, when sea level was much lower and the North American Plate was further south. Davidson Seamount is an inactive volcanic undersea mountain habitat off the coast of central California and is one of the largest known seamounts in US waters. From base to crest, it is 2,280 m tall, yet its summit is still 1,250 m below the sea surface.

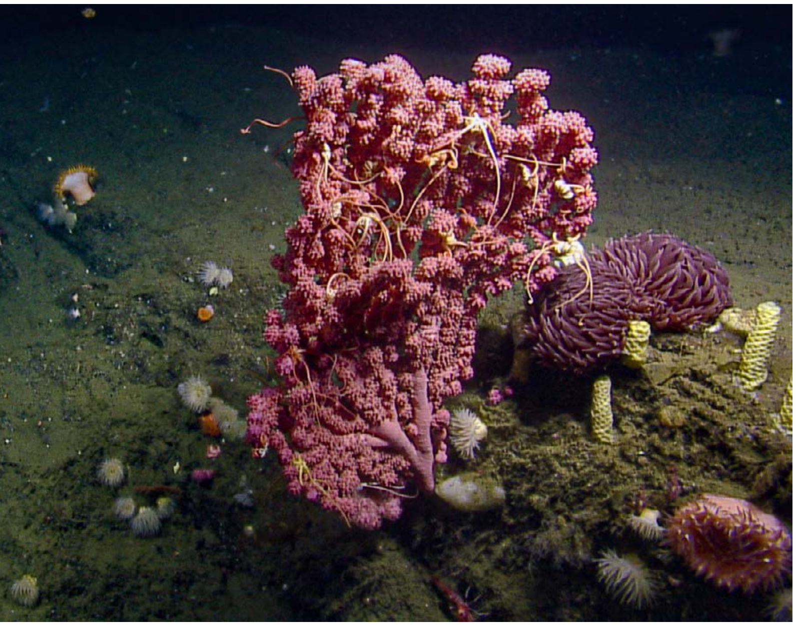


FIGURE 1 (above). This pink bubblegum coral (*Paragorgia* sp.), perched higher than the seafloor for better access to food in the water column, is home to at least 15 brittle stars (Class Ophiuroidea). Other organisms in view include pom-pom anemone (*Liponema brevicorne*), egg case columns from the snail *Neptunea*, and various anemones.

FIGURE 2 (right). Using the manipulator arm, ROV *Hercules* collects a bamboo coral colony (*Keratoisis* sp.) for determination of the age of the colony and past climate conditions to better understand the extent of ocean acidification and impacts from climate change.

PIONEER CANYON

In 2016, ROVs *Hercules* and *Argus* conducted exploratory surveys of the habitat and biological communities in Pioneer Canyon, providing a quick glimpse of its diversity of corals and sponges (Roletto et al., 2017). The main objectives for the 2020 cruise were to describe the extent of deep-sea corals, sponges, and associated invertebrates and fishes in the western portion of the canyon and surrounding rocky substrate by conducting exploratory and quantifiable ROV transects in the deeper portions of the canyon, from 800 m to 1,500 m water depth.

Two 24-hour dives revealed a variety of canyon habitats ranging from gently sloped, soft sediments with sea pens and benthic fishes, to fractured rocky cobbles and boulders with numerous sea fan corals and sponges, to steep rocky terrain with numerous bamboo and bubblegum corals (Figure 1). Seventeen biological samples were collected (e.g., sponges, corals, drift algae) for taxonomy, in addition to nine water samples for eDNA, coral aging, ocean acidification, and associated microplastics studies (Figure 2), and one sediment sample for examining past ocean conditions.

DAVIDSON SEAMOUNT REGION

In 2018 and 2019, E/V *Nautilus* expeditions discovered extensive octopus nurseries in at least two areas in the southeastern flanks of Davidson Seamount at 3,200 m depth (King and Brown, 2019; King et al., 2020). These nurseries each featured thousands of mother octopus brooding their eggs within low temperature seeps (up to 10.4°C). Also in 2019, we came across an extremely rare find: a relatively fresh whale fall (i.e., a dead whale that was on the seafloor for approximately four months). Samples revealed a new

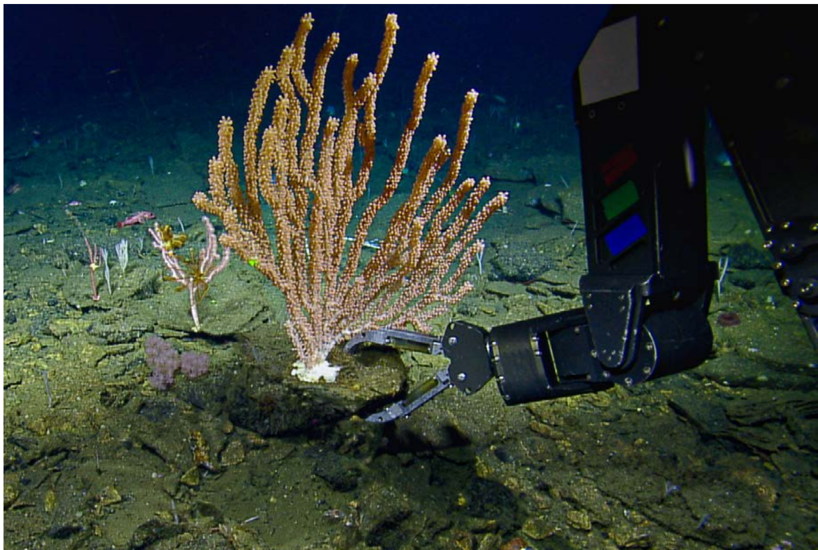


FIGURE 3. Aggregation of brooding octopus (*Muusoctopus robustus*) mothers clustered around a low-temperature seep along with pale-yellow matted tubeworms that often are associated with these seeps.

species of bone-eating worm, *Osedax*, that was living on the whale's bones. Both of these unique areas were our high-priority targets for further exploration and sampling. The main objectives for this portion of the expedition were to fully survey a second octopus nursery, revisit the whale fall for video characterization, collect *Osedax* from the whale, and explore new areas near Davidson Seamount and an unexplored volcanic ridge south of Davidson.

A 22-hour dive near the seamount surveyed extensive aggregations of brooding octopus at the top of a small volcanic cone and then transited 2 km to revisit the whale fall. During 10 hours of video footage, we surveyed approximately 15 acres of seafloor and counted 3,647 octopus, of which 2,938 (81%) were brooding mothers (Figure 3). Visual inspection of several egg masses confirmed embryonic development, and several hatching events were observed. The temperature of seeping water was elevated, up to 9.4°C, with corresponding lower dissolved oxygen levels. The whale fall was more decomposed than we expected, but flourishing populations of *Osedax* and ampheretid worms were still present (Figure 4). Whale bones, *Osedax*, baleen, worms, sediment, in situ seawater, and other samples were collected. Video orbits made around the whale fall will be used to construct a three-dimensional model for comparison with the one generated in 2019 (https://tinyurl.com/y47urv2j). This whale fall was recently confirmed to be a mature minke whale (*Balaenoptera acutorostrata*) by California Academy of Sciences mammalogy staff and Robert Boessenecker (College of Charleston, *pers. comm.*) based on the curvature of the mandibles and closure of bone fissures.

An 18-hour dive was completed at an unexplored region southwest of Davidson Seamount. The seafloor featured a variety of basalt formations, including pillow lavas and flows with high rugosity, and was cleaved in places by vertical walls. Although no additional warm-water seeps or octopus nurseries were found, corals and sponges observed during all three dives will be identified and counted via video analyses. It is important to note these remote and deep waters are not immune to visible human impacts, as we observed marine debris such as baking pans, metal crates, paint buckets, garbage bags, and soda cans.

During the cruise, a live-streamed "Explore from Home" virtual event reached over 2,200 viewers, with over 10,780 views across platforms. The NautilusLive.org live streams received over 365,000 views during this cruise, with viewers tuning in for 65,000 hours of total watch time. Twenty-four virtual education events were hosted by staff from MBNMS (16 events) and Greater Farallones National Marine Sanctuary (8 events) with 514 students to raise awareness and support the expedition. Video highlights (https://nautiluslive.org/cruise/NA122) from the expedition were shared via NautilusLive.org and social media accounts on YouTube, Facebook, Instagram, and Twitter.

The deep waters of the sanctuaries are rarely explored, and the ROV dives reveal many secrets of North America's most ecologically rich underwater treasures off central California. *Nautilus* cruises greatly expand our understanding of the diversity and richness of the deep-sea communities in our national marine sanctuaries. Confirming the presence of dense, long-lived corals and rare and unique discoveries like the thousands of brooding octopuses and the whale fall in the "foothills" of Davidson Seamount are excellent examples of the need for further investigation and quantification.

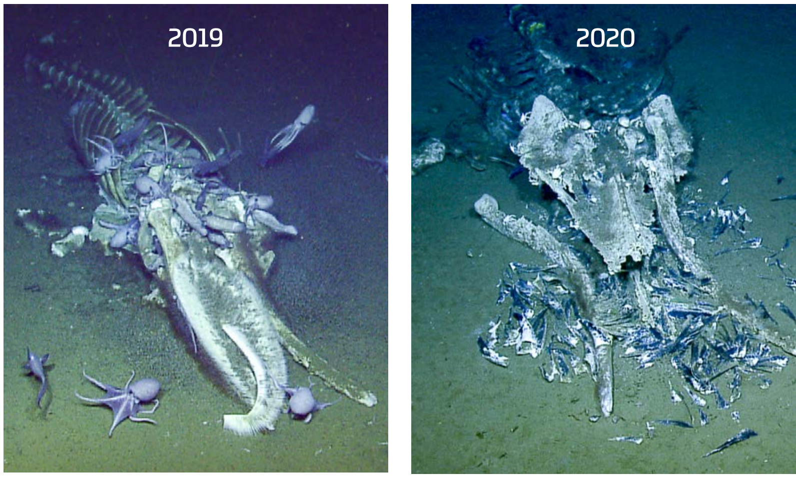


FIGURE 4. Comparison of the minke whale fall as surveyed in October 2019 (left) and October 2020 (right). When first discovered, the fall was estimated to have been on the seafloor for approximately four months.

California Streaming

Exploring Deep-Sea Coral and Sponge Assemblages in Sunny Southern California

By Elizabeth Duncan, Lisa Wooninck, Tom Laidig, Elizabeth Clarke, Abigail Powell, Curt Whitmire, Guy Cochrane, and Chris Caldow

In October 2020, E/V *Nautilus* explored the Santa Lucia Bank area and the Channel Islands National Marine Sanctuary (CINMS) and surrounding waters offshore of California. This expedition furthered research priorities shared by the West Coast Deep-Sea Coral Initiative, the EXpanding Pacific Research and Exploration of Submerged Systems (EXPRESS) campaign, and other research initiatives to document the distribution of deep-sea resources. Santa Lucia Bank is an area of interest for the development of offshore wind energy and is also within the nominated Chumash Heritage National Marine Sanctuary (CHNMS). Eleven ROV dives were conducted in the designated and proposed national marine sanctuaries to validate seafloor mapping data and habitat suitability models for deep-sea corals and sponges, and to better understand the distribution and connectivity of these habitats via targeted sampling. This work largely occurred in previously unexplored areas and will likely inform future regional research and management decisions.

SANTA LUCIA BANK: FIRST LOOK AT FRACTURED FEATURES AND FILTER FEEDERS

Deep-sea corals and sponges are sessile filter feeders that require hard and stable substrate to settle and grow and current flow for food delivery. Created by tectonic uplift, Santa Lucia Bank is within a seismically active region, bounded by faults to the east and west. As a result of the long history of stress, the thinly bedded Miocene or older metasedimentary rocks are highly fractured. During ROV explorations on the flanks of the bank, we observed a field of talus between 1,200 m and 1,500 m depth, likely earthquake-induced landslide deposits. During our and partner ROV dives, we noted that much of the bank harbors relatively few and small coral and sponge specimens. However, at 1,000 m depth, while crossing a very steeply sloping scarp of a northwest-trending fault, we observed for the first time large coral species, including bubblegum corals (Figure 1) and primnoids (*Parastenella* sp.), as well as large barrel and goiter sponges.

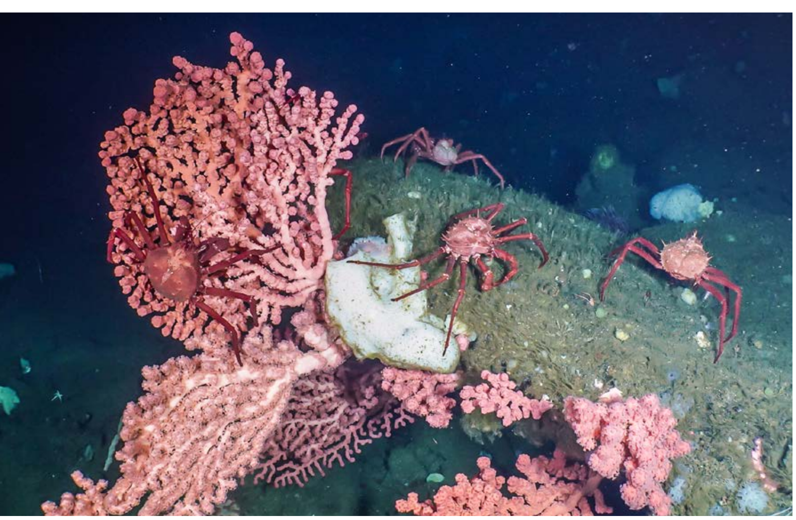
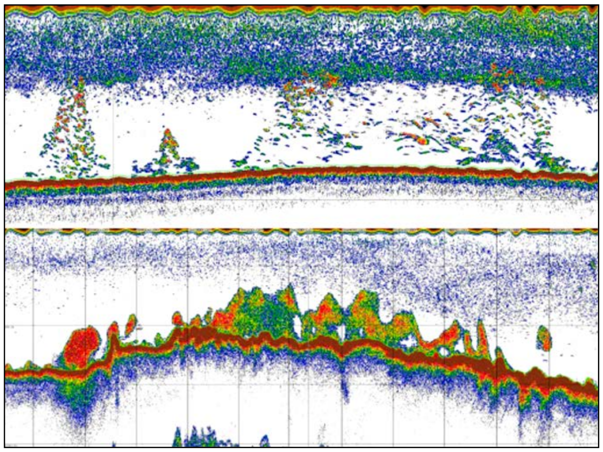


FIGURE 1 (above). Large bubblegum corals co-occur with California king crabs at the ridge of a fault scarp on Santa Lucia Bank.

PILES OF PETRALE SOLE IN SUSPECTED SPAWNING STATION

After exploring the deeper areas of the Santa Lucia Bank and escarpment, deteriorating weather chased us inshore where we completed a short dive in an area surveyed with an autonomous underwater vehicle (AUV) in 2005 and 2018. The 2018 AUV imagery revealed what appeared to be a petrale sole spawning aggregation. Petrale sole (*Eopsetta jordani*) are commercially important flatfish known to carry out seasonal migrations to reproduce, but information on the timing and location of spawning is limited. This was a great opportunity to determine the persistence of a suspected spawning area and to attempt to film courtship behavior. During the dive, we were excited to find high densities of petrale sole present and observed fish clustered together in groups similar to those seen in 2018 images (Figure 2). Filming courtship behavior was difficult as the petrale sole were easily disturbed by the ROV's presence; however, we completed a number of transects that we'll use to estimate their abundance. Preliminary analysis indicates that the highest densities of petrale sole were located on a slightly different part of the rocky feature than in 2018.

FIGURE 2 (below). A petrale sole rests its head on the body of another. Observed in numerous individuals and documented in other flatfish species, we hypothesize that this behavior is part of petrale sole courtship activity. Flatfishes have sensory organs on their dorsal and ventral surfaces so it may provide an opportunity for the exchange of chemical cues.



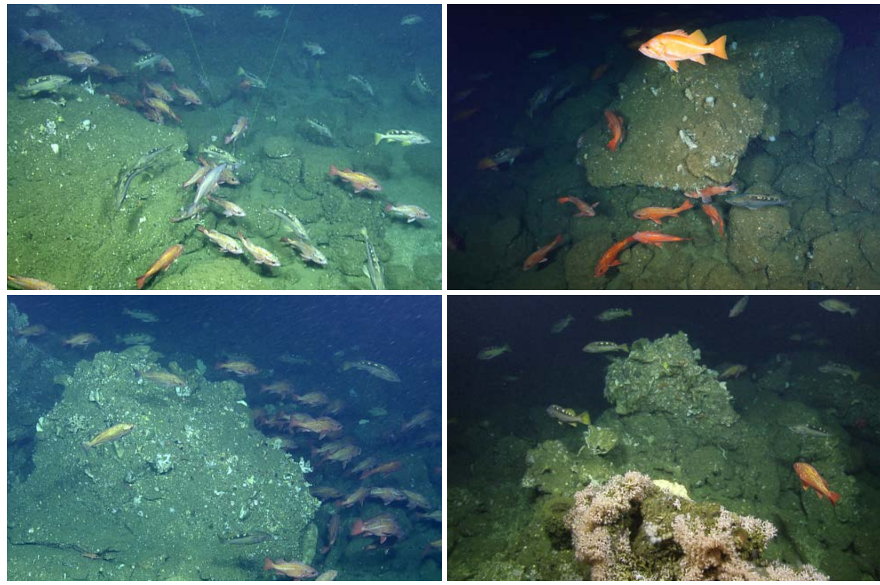


FIGURE 3. EK60 echograms collected aboard NOAA Ship *Bell M. Shimada* in 2016 depict fish communities in the vicinity of Richardson Rock. Photos from the Richardson Rock Marine Reserve show high densities of rockfish encountered.

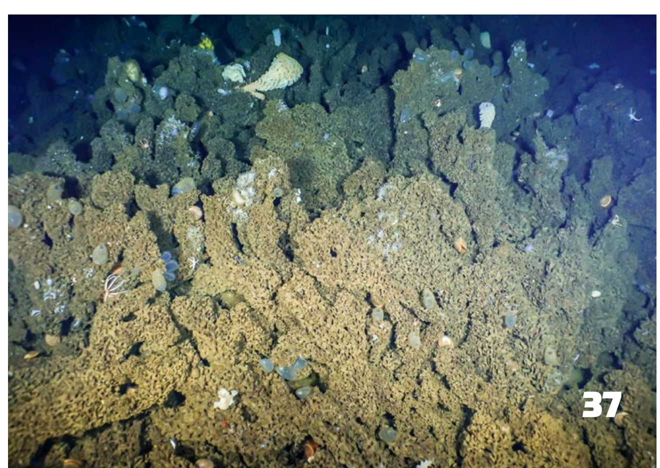
RICHARDSON ROCK MARINE RESERVE, RIFE WITH RELIEF AND ROCKFISH

Following Santa Lucia Bank, *Nautilus* transited south into CINMS to survey the Richardson Rock Marine Reserve, a relatively shallow area west of San Miguel Island. In 2016, sonar surveys conducted here revealed complex rocky habitat and high fish biomass (Figure 3). While we were able to quantify fish abundance in the region throughout the entire water column, we were unable to identify the species or count those resting on the bottom. This latter point is particularly critical during night surveys while many fish rest along the seafloor. During the 2020 *Nautilus* mission, however, we were able to visually identify the species likely detected during the earlier sonar surveys. We encountered hundreds of vermilion rockfish (*Sebastes miniatus*) in the rocky areas and few fishes in the soft sediments, similar to the patterns observed in 2016. Vermilions were an order of magnitude more abundant in rocky habitat than other common species, like bocaccio (*S. paucispinis*), speckled (*S. ovalis*), and olive rockfishes (*S. serranoides*) (Figure 3). The species observed well above the seafloor in 2016 may be olive and speckled rockfishes, while those near the seafloor may be bocaccio and vermilion rockfish. However, since the 2020 ROV surveys were conducted at night, we can't quantify the overall abundances of all species, because many were resting within rock crevices. Additional daytime surveys are needed to confirm this hypothesis.

DEEP DISCOVERY: STEADFAST SPONGE SKELETONS OBSERVED IN FOOTPRINT MARINE RESERVE

Within CINMS, the most unexpected discovery occurred while exploring a deeper portion of Footprint Marine Reserve. Between two well-studied banks southeast of Santa Cruz Island, we came across a vast landscape of dead glass sponge skeletons. Although most of the sponge material was dead, there were a few patches of living tissue (Figure 4). Upon closer inspection, the mounds appeared to be composed of a sponge in the genus *Farrea*. While most sponges disintegrate when they die, glass sponges like *Farrea* have fused skeletons that can persist long after the sponge dies. The remnant skeletons provide hard habitat that other species can attach to and grow on, and we observed numerous other sponge species and tunicates growing atop the dead mounds. This discovery has sparked a number of key research questions: How thick are these sponge mounds and how far do they extend? Why did they form at this location? How old are they? Why did they die? How similar or different are they to sponge reefs found off British Columbia and Alaska? We will begin a preliminary investigation using the environmental and acoustic data collected by *Nautilus* alongside samples of live and dead sponges collected by the ROV.

FIGURE 4. Estimated to be several meters tall in some areas, the mounds of dead glass sponge discovered during this expedition covered thousands of square meters. The total area is unknown, but researchers hope to find the assemblage's signature in the sub-bottom profiling data collected by OET during earlier mapping missions.



Biodiversity Baselines and Biopharmaceutical Potential for the Borderland

By Lisa Levin, Paul Jensen, Greg Rouse, Kira Mizell, Gabriel Castro-Falcón, Kaila Pearson, Kaitlin Creamer, Devin Vlach, Steven Auscavitch, and Dwight F. Coleman

A team of ecologists, microbiologists, zoologists, and a geologist explored the Southern California Borderland from October 27 to November 6, 2020. The cruise goals 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 associated with phosphorites and ferromanganese crusts. We sought to characterize fish and benthic megafauna and macrofauna associated with these hardground habitats as well as the microbial communities associated with sediments, mineral surfaces, and select invertebrates.

Operations consisted of sonar-based mapping by E/V *Nautilus*, an ROV *Argus* test dive, and ROV *Hercules*/*Argus* dives during which we conducted biodiversity surveys and collected samples in conjunction with hydrographic data collection via an ROV-mounted CTD. ROV work was conducted from 1,800 m to 100 m depth at eight sites located 65 km to 240 km offshore of southern California, including Patton Ridge, San Juan Seamount, Northeast Bank, Cortes Bank, 40-Mile Bank, San Clemente Escarpment, and Osborn Bank (Figure 1). During each eight-hour dive, four to six 100 m-long video transects were conducted for habitat and biodiversity analysis, and samples of megafauna, sediments, rocks, and water were collected for microbiological, animal, and mineral substrate analyses. On San Juan Seamount and 40-Mile Bank, a set of colonization substrates (wood, bone, carbonate, ferromanganese crust on basalt, and phosphorite rock) were deployed at about 1,050–1,100 m and at 693 m depths within the oxygen minimum zone core; they will be recovered in one year. Mapping conducted between ROV dives filled in bathymetric and backscatter data gaps on transits between study sites.

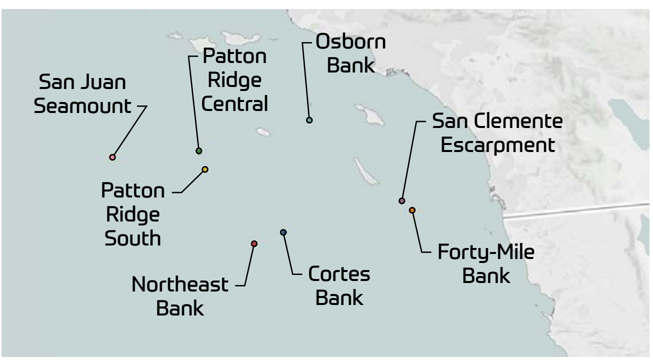


FIGURE 1. Map of ROV *Hercules* dive sites.

Complicated tectonics create the rough topography of the Southern California Borderland, which includes a series of banks, ridges, knolls, seamounts, and escarpments. Each of these geologic edifices provide exposed rock hardgrounds that can act as biological substrates and habitats. The presence of an oxygen minimum zone (<20 µMol O_2) combined with stronger currents that reduce sedimentation, especially at depths below 850 m, has resulted in the precipitation of ferromanganese crusts on the exposed surfaces of basalts and sedimentary rocks. Phosphorites are also prevalent in the region. Both phosphorites (Figure 2a) and ferromanganese crusts (Figure 2b) can contain metals at high enough concentrations to be considered as potential mineral resources. Although no

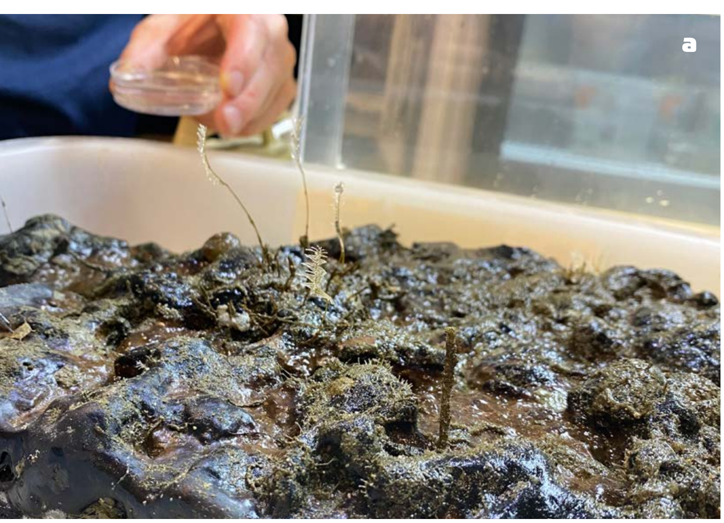


FIGURE 2. (a) Phosphorite rock with fauna collected on Cortes Bank. (b) Ferromanganese crust collected on San Juan Seamount.

FIGURE 3 (left). Brisingid starfish and sponges imaged on San Juan Seamount.

FIGURE 4 (below). Sedimentary oblate rock showing fossilized marine mammal with exposed rib cage.

exploitation of either marine mineral type has occurred anywhere in the deep sea, and there is currently no interest in resource exploration in the Southern California Borderland, a multidisciplinary research effort such as ours, examining marine mineral and concomitant ecosystem resources, can inform decisions about their potential exploitation.

The hardgrounds appear to host a moderately high diversity of megafauna, macrofauna, and fish, and in some places, high densities of animals. Different taxa dominate the megafaunal assemblages in each place visited. Both offshore/inshore and depth/oxygen differences were evident. The base of escarpments, banks, and ridges were typically sediment-covered, with high densities of sea cucumbers (*Scotoplanes*), sea pens (*Halipteris or Anthoptilum*), other cnidarians (*Umbellula*), brittle stars, and other taxa. Oxygen availability appears to exert a strong influence on the hardground biota; zonation of assemblages on the slopes and flanks of the explored features was evident between 1,100 m and 500 m depth. Dense bands of brittle stars or zones of abundant brisingid starfish (Figure 3), sponges (*Hyalonema, Mycale, Farrea, Abestopluma, Heterochone*), sea cucumbers (*Pannychia, Psolus,* and others), sea urchins (*Araesoma, Asthenosoma*), or bivalves (*Acesta*) were observed, possibly reflecting oxygen minimum zone edge effects (oxygen thresholds intersecting with high food availability). Corals such as bubblegum coral (*Paragorgia*) and *Swiftia* were common at shallower depths (<600 m). Crabs (*Paralomis*) were common, and kelp falls (mixed with *Phyllospadix* seagrass), observed at Patten Ridge South and 40-Mile Bank, were characteristically colonized by pink urchins (*Strongylocentrotus fragilis)* and small consumers (amphipods or dorvilleid polychaetes). Large erosional carbonate discs were observed on Cortes Bank (which previously was subaerially exposed), with one containing the fossilized skeleton of a marine mammal, likely a juvenile whale (Figure 4). Fishing gear and debris (soda cans, lost instrumentation, cable connectors) were observed on the seafloor on many of the dives.

Rocks, sediments, invertebrates, and water collected by the ROV manipulator, push cores, vacuum slurp, and Niskin bottles will be studied further to determine the biopharmacological properties of associated bacteria. We will use a culture-dependent approach to grow and isolate individual colonies of Actinobacteria, which are prolific producers of molecules that have been used clinically to treat numerous ailments. Culture collections of these isolated bacteria will be screened to find whether they inhibit bacterial and cancerous cell growth. Additionally, we will assess the microbiome of the samples using a culture-independent approach. Metagenomics and amplicon sequencing will be used to find and compare genes putatively involved in the generation of medicinal metabolites and to assess the overall microbial community. This will allow us to evaluate the biopharmacological potential of a broader range of bacteria and compare microbial diversity across the samples.

It is currently unclear whether the animal and microbial communities occupying phosphorite or ferromanganese crust differ. To investigate this further, we will consider the location, water depth, seawater oxygen, mineral texture, and geochemical composition of each sample and their correlations with the associated biological communities. This analysis will elucidate the dominant factors controlling their diversity and abundance.

UPDATES FROM THE NOAA OCEAN EXPLORATION COOPERATIVE INSTITUTE

By Adam Soule, Andrew Bowen, Brian Connon, Monty Graham, Allison Fundis, Larry Mayer, Richard W. Murray, and Robert D. Ballard

UNIVERSITY OF RHODE ISLAND

Ocean exploration remains a cornerstone research priority of the University of Rhode Island's Graduate School of Oceanography, the lead institution for the Ocean Exploration Cooperative Institute (OECI). Among significant changes in OECI leadership over this past year, Paula Bontempi was appointed as Dean of the Graduate School of Oceanography and assumed the role of OECI principal investigator. She came to URI from NASA where she served as Program Scientist for the Ocean Biology and Biogeochemistry program as well as Deputy Director for the Earth Science Division. Adam Soule joined the URI/GSO staff and assumed the role of OECI Executive Director as well as Director of the Center for Ocean Exploration. He was previously at the Woods Hole Oceanographic Institution (WHOI) where he developed an active marine geology research program focused on submarine volcanism and served as Chief Scientist for Deep Submergence. Both are excited about the collaboration between the OECI partner institutions and the NOAA Office of Exploration and Research and the coming technology developments that will accelerate exploration and discovery for ocean science, the blue economy, and beyond.

The Inner Space Center at URI/GSO continued to support OECI seagoing activities over the past year by providing telepresence support to E/V *Nautilus*. In addition, the ISC tested hardware and software and developed plans to support the next generation of telepresence to enable tele-engineering, tele-operations, and tele-science and to expand telepresence capabilities to a greater range of platforms. The OECI focus on Telepresence 2.0 aims to leverage increasing availability of high-bandwidth satellite communications to enable smaller ships, such as the new Regional Class Research Vessels operated by URI, the University of Southern Mississippi (USM), and Oregon State University (OSU), as well as envisioned NOAA vessels, to execute the full range of deep submergence science, even with decreased shipboard staffing. This need for meaningful science at reduced staffing levels was brought into clear focus during the past year, as COVID-19 protocols severely limited berthing on seagoing research expeditions. The ISC preparatory activities will be field-tested in the coming months as additional OECI expeditions delayed by COVID-19 are executed.

Another addition to the OECI team at GSO/URI this past year was graduate student Coralie Rodriguez, who is conducting geochemical analyses of ferromanganese crusts recovered during previous NOAA-supported OET expeditions. She has also begun analytical work for high-precision analyses of rare earth elements in ferromanganese crusts and looks forward to participating in seagoing activities and serving as an ambassador to the next generation of ocean explorers.

OCEAN EXPLORATION TRUST

OECI efforts in 2020 included two E/V *Nautilus* expeditions: NA124 (Benthic Communities Across Mineral-Rich Biomes, pages 38–39) and the Southern California Borderland EEZ mapping expedition (pages 28–29), which collectively mapped 37,489 km^2 of the US EEZ and conducted 10 ROV dives for visual and sampling surveys. Due to impacts of the ongoing COVID-19 pandemic, both expeditions relied on additional support from shore-based teams via telepresence for science and outreach (pages 26–27).

Shore-based team members successfully processed newly acquired multibeam bathymetry data while the ship was conducting seafloor mapping surveys. This newly tested ability has implications for broadening participation to shore-based groups well beyond operating under the constraints of a pandemic.

In 2020, OET also collaborated with WHOI and the University of New Hampshire (UNH) to prepare for technological demonstrations of new autonomous vehicle systems that are slated for 2021 operations aboard E/V *Nautilus*. The expectation for these technology demonstration expeditions is that they will lead to the development of new operational concepts that will enhance ocean exploration capabilities for the community at large. Examples include concurrent operations using multiple autonomous systems that communicate with each other via subsea optical links and conducting engineering and operational tasks via telepresence. WHOI and OET will demonstrate *Nereid Under Ice* (NUI) vehicle subsea optical communication and operations with ROV *Argus* in 2021 aboard E/V *Nautilus*, an effort that was delayed from 2020 due to the pandemic.

In 2021, WHOI and UNH engineers and scientists will join a second OECI technology demonstration cruise that will concurrently operate WHOI's midwater autonomous vehicle *Mesobot* and UNH's newly acquired iXblue autonomous surface vessel (ASV) DriX. *Mesobot* will be used to collect water-column data and eDNA water samples offshore Southern California, and UNH—in collaboration with OET—will demonstrate operations and shallow (up to 500 m depth) bathymetry acquisition with DriX.

Preparation for the upcoming technological demonstrations and system integrations with *Nautilus* are well underway, including a 4 m extension of the ship's stern and the addition of a new crane and launch and recovery system. Depending on pandemic conditions in 2021, OET will also continue OECI collaborations with Tuskegee University and the University of Southern Mississippi through at-sea internship opportunities for Tuskegee undergraduates.

UNIVERSITY OF NEW HAMPSHIRE

Over the past year, the UNH OECI team has been fully focused on working closely with iXblue and the OECI partners on design and construction of an innovative ASV concept that will allow for the collection of high-quality bathymetric data at high speed and also support the launch and recovery of multiple vehicles (i.e., ROVs, ASVs, AUVs) using the same system.

In its initial configuration, the ASV DriX will have a Kongsberg EM 2040 multibeam sonar for seafloor mapping, 200 kHz and 70 kHz fisheries sonars for midwater mapping, and a Sonardyne HPT 3000 transceiver for ultrashort baseline tracking and acoustic communications with other vehicles. A unique "universal delivery system" (UDS) has been designed to launch and recover the DriX with an articulated crane and then launch and recover an AUV (Figure 1). The ability to launch and recover both surface and underwater vehicles using the same system will allow operation of both systems during the same mission, increasing survey efficiency while occupying minimal deck space. It also opens up the potential for a range of collaborative activities between multiple vehicles, including the use of the ASV as a relay station for high-bandwidth data collected by the AUV, potentially allowing real-time, high-bandwidth transmission from the AUV to the mother ship and/or shore.

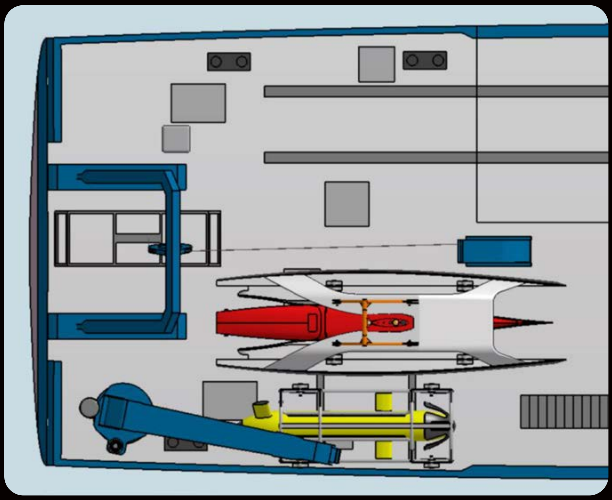
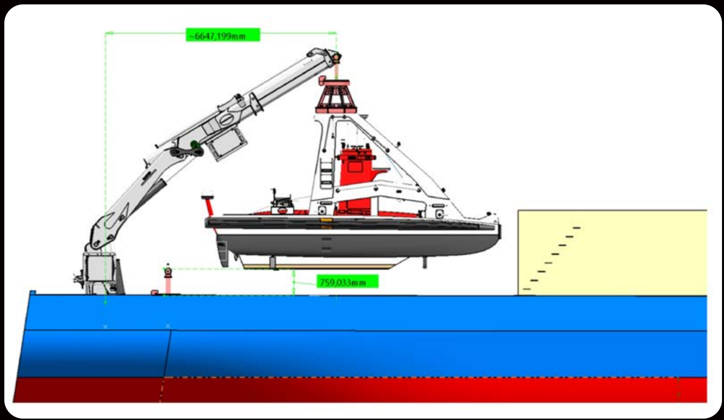


FIGURE 1. A unique "universal delivery system" features an articulated crane with docking head designed to launch and recover both autonomous surface and autonomous underwater vehicles.



UNIVERSITY OF SOUTHERN MISSISSIPPI

The University of Southern Mississippi highlights ocean exploration and mapping activities as part of an overall portfolio of ocean hydrographic sciences. The backbone infrastructure supporting ocean exploration at USM includes the uncrewed 2,000 m depth maritime systems *Eagle Ray* and *Mola Mola*. *Eagle Ray* is a mapping AUV outfitted with a multibeam sonar, and *Mola Mola* is an imaging AUV. The OECI took advantage of USM's R/V *Point Sur* to conduct engineering tests following upgrades to *Eagle Ray* mechanical and electrical systems that included enhancements to the diving controls and surfaces and topside communications. The new launch and recovery system further improved the safety and handling of *Eagle Ray* under higher sea states.

An eight-day expedition intended use AUVs *Eagle Ray* and *Mola Mola* to map Viosca Knoll, the site of a shipwreck discovered in 2003 in the Gulf of Mexico, was scheduled for early June 2020 but was rescheduled to July 1–8 due to COVID-19 restrictions. Weather and technical challenges shifted operations to an area known as Mountain Top Bank, where successful mapping was conducted along with *Mola Mola* imaging surveys of a previously uncharacterized mesophotic reef (Figure 2). During this cruise, USM also demonstrated the ability to operate multiple uncrewed maritime systems from R/V *Point Sur*, including *Eagle Ray*, *Mola Mola*, a 5 m unmanned surface vehicle, and ocean gliders.

USM's longstanding Marine Education Center, working under the OECI, continues to collaborate with Tuskegee University (Alabama) to bring underrepresented minority students into internships hosted by OECI partners. Although COVID-19 restricted progress in 2020, USM assisted Tuskegee University in establishing a thriving Ocean Exploration Club.

WOODS HOLE OCEANOGRAPHIC INSTITUTION

The WHOI team prepared for a two-expedition field program initially planned to begin in February 2020 with a cruise to demonstrate the simultaneous operation of an ROV and an AUV. This demonstration would have marked the first use of new short-range subsea optical communications to establish high-bandwidth communications and real-time control of AUV *Nereid Under Ice* and ROV *Little Hercules*. These trials were planned to include transmission of NUI data via the optical modem and *Little Hercules* to the operators on board the tending vessel. This cruise was canceled and moved to June 2021 aboard E/V *Nautilus* when the tests will use *Argus* instead of *Little Hercule*s. The WHOI team also plans to use the NUI optical link for other AUV missions and explore the potential for real-time control of the AUVs to accomplish tetherless sampling tasks.

The second expedition, initially planned for *Point Sur*, was intended to deploy the *Nereid Hybrid Tethered* (NHT) vehicle (Figure 3). Unlike NUI, NHT is an ROV with

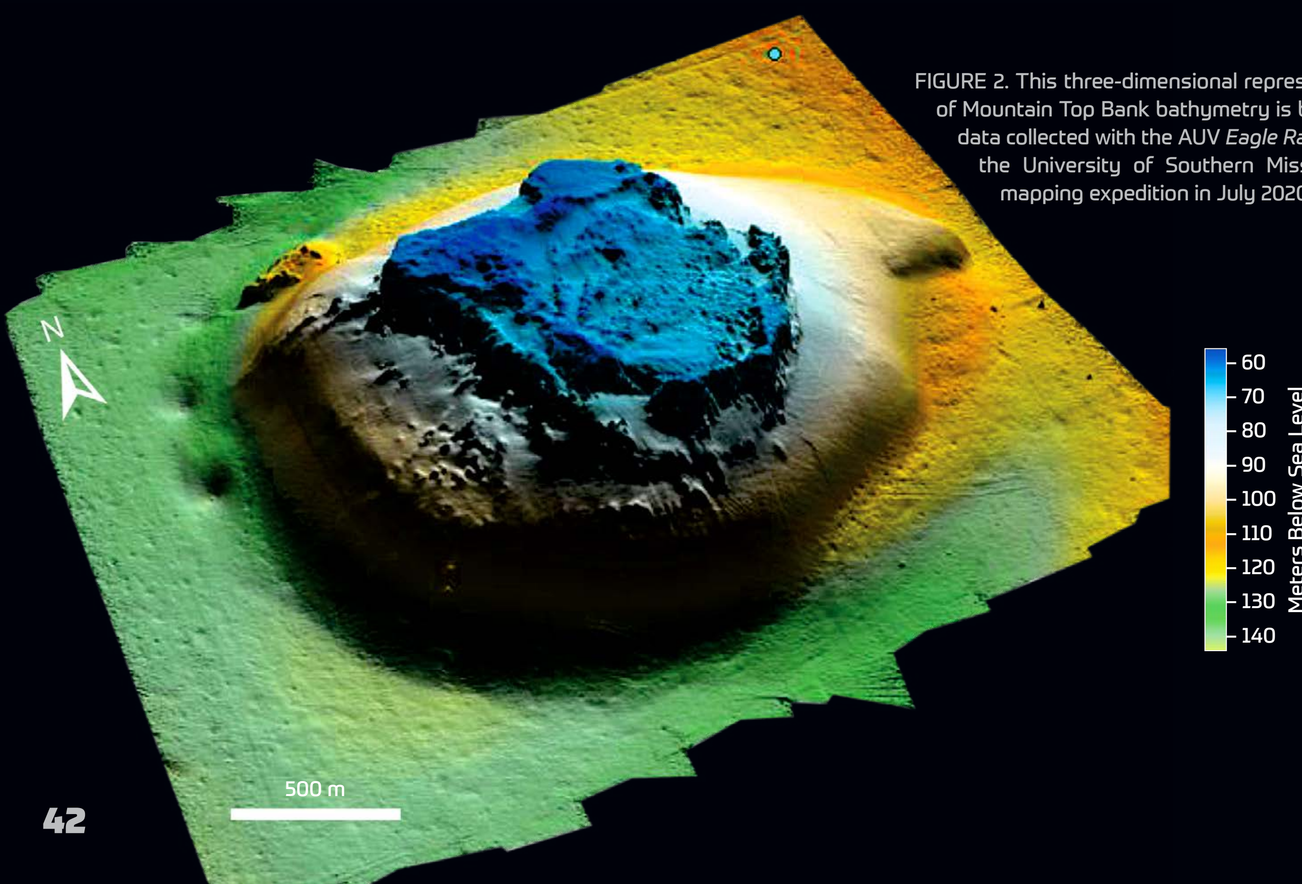


FIGURE 2. This three-dimensional representation of Mountain Top Bank bathymetry is based on data collected with the AUV *Eagle Ray* during the University of Southern Mississippi's mapping expedition in July 2020.

a reusable lightweight tether ideal for deployment from smaller vessels. This system provides the ability to operate ROVs from smaller ships in far deeper waters and with less impact than would be possible with conventional ROV systems. Such reusable lightweight tether systems will enable sampling and characterization tasks aboard a larger number of NOAA vessels and will pave the way for future autonomous surface craft to support such missions. The second expedition was also canceled due to the emerging COVID-19 pandemic, and the programs of the two originally proposed NHT cruises have now been merged into one field program planned for 2021. The NUI vehicle can "stand in" for the NHT platform and is being modified to accommodate use of the small diameter reusable tether. A small portable winch from the UNOLS wire pool has been identified and will be installed temporarily on *Nautilus* for this part of the test and demonstration.

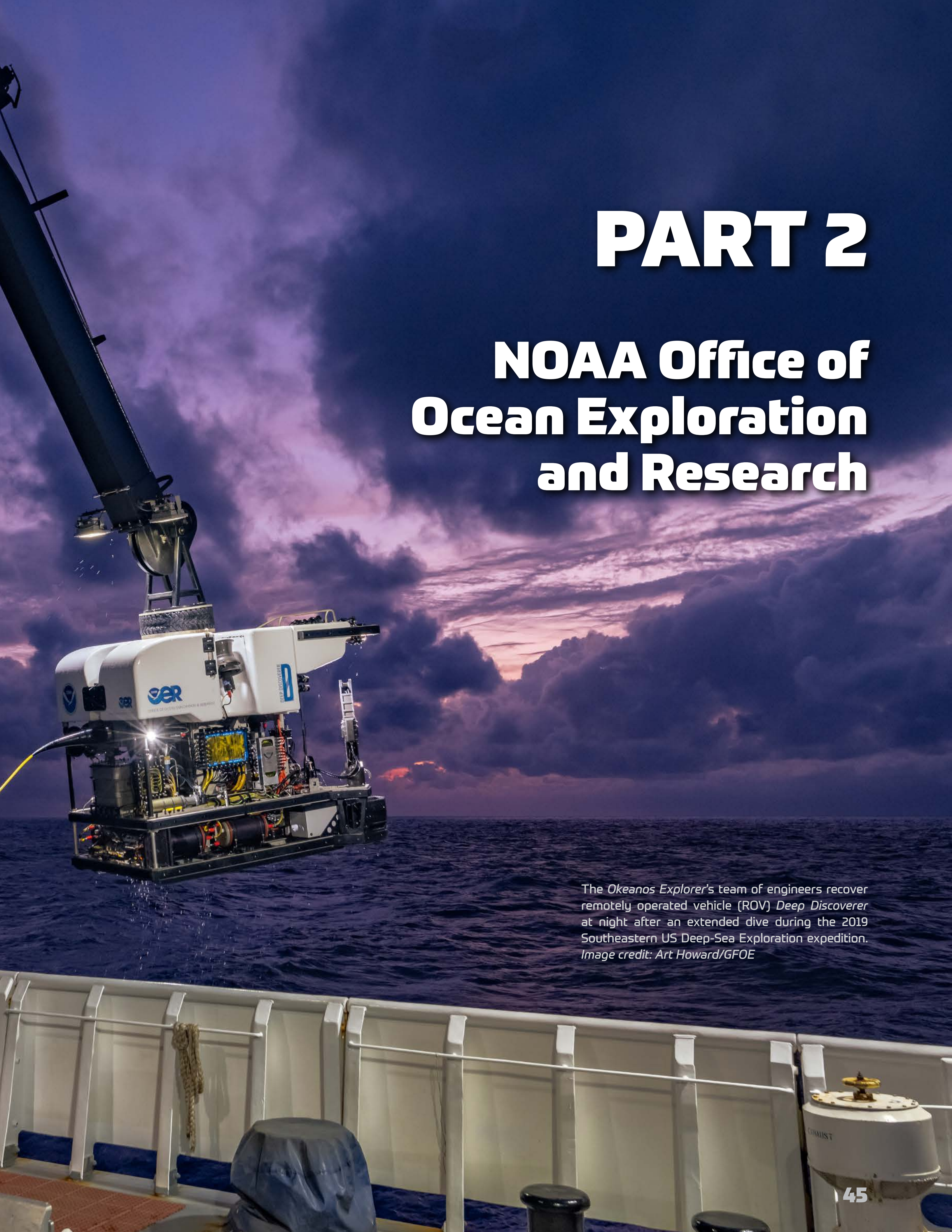
In addition to the work outlined here, WHOI developed a full team of participants who are embedded within and contributing to the various OECI working groups. During this time, the WHOI principal investigator was transitioned from former President Mark Abbott to Vice President for Research Rick Murray.

FIGURE 3. The *Nereid Hybrid Tethered* vehicle shown during a recent NOAA OER-funded expedition to Gakkel Ridge (Arctic Ocean) aboard the Norwegian icebreaker *Kron Prins Hakkon* is an important component in OECI's technology development. *Image credit: Luis Lamar*

Although the COVID-19 pandemic has significantly impacted our projects, the WHOI OECI team is now actively planning programs to be undertaken in 2021. Julie Huber's expedition to the Mariana back-arc basin with Schmidt Ocean Institute has been deferred until later in 2021, and Tim Shank's work with *Orpheus* was deferred from October 2020 until May 2021. *Mesobot* will be used by Dana Yoerger and his team on a cruise aboard E/V *Nautilus* (Figure 4). Over the last several months, *Mesobot* has been upgraded in preparation for this work; a short series of trials in Bermuda's waters will be undertaken prior to the deployment from *Nautilus*.

FIGURE 4. Deployment of the autonomous underwater vehicle *Mesobot* from R/V *Neil Armstrong* during a March 2020 cruise off the northeast US continental shelf. *Mesobot* was developed through a collaboration between WHOI, the Monterey Bay Aquarium Research Institute, Stanford University, and the University of Texas Rio Grande Valley, and it was funded by NSF and the WHOI Ocean Twilight Zone Project. *Image credit: Ken Kostel, ©Woods Hole Oceanographic Institution*

Note: All images and graphics in the NOAA section of this publication are credited to the NOAA Office of Ocean Exploration and Research unless otherwise indicated.



PART 2

NOAA Office of Ocean Exploration and Research

The *Okeanos Explorer*'s team of engineers recover remotely operated vehicle (ROV) *Deep Discoverer* at night after an extended dive during the 2019 Southeastern US Deep-Sea Exploration expedition. *Image credit: Art Howard/GFOE*

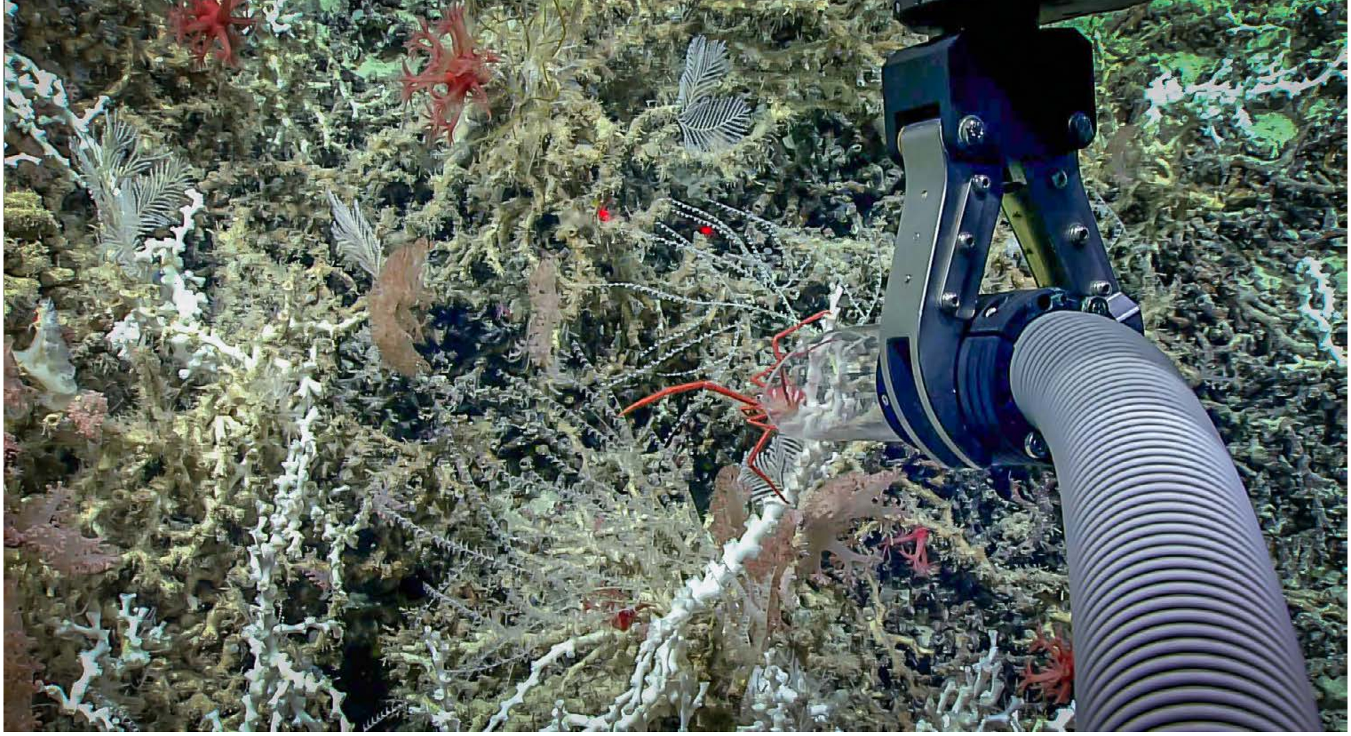
Introduction

Looking Back and Looking Forward with the National Strategy for Mapping, Exploring, and Characterizing the US Exclusive Economic Zone

Two decades ago, the United States launched a national strategy to improve our understanding of the ocean by establishing a new exploration program in US waters. A panel of leading ocean explorers, scientists, and educators met and then presented their recommendations in the 2001 report *Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration* (President's Panel on Ocean Exploration, 2001). The report set out a plan to explore new areas, embrace multidisciplinary exploration approaches, challenge existing technologies, and accept the risks of exploration when the benefits are unknown. The report led to the creation of the NOAA Office of Ocean Exploration and Research (OER), which today has an annual budget appropriation of $43 million, leads expeditions on NOAA Ship *Okeanos Explorer*, and funds scientists each year through a federally funded opportunities program. Along the way, OER has built valuable partnerships with academic institutions, private industry, and federal agencies to leverage exploration efforts that would be impossible to accomplish alone.

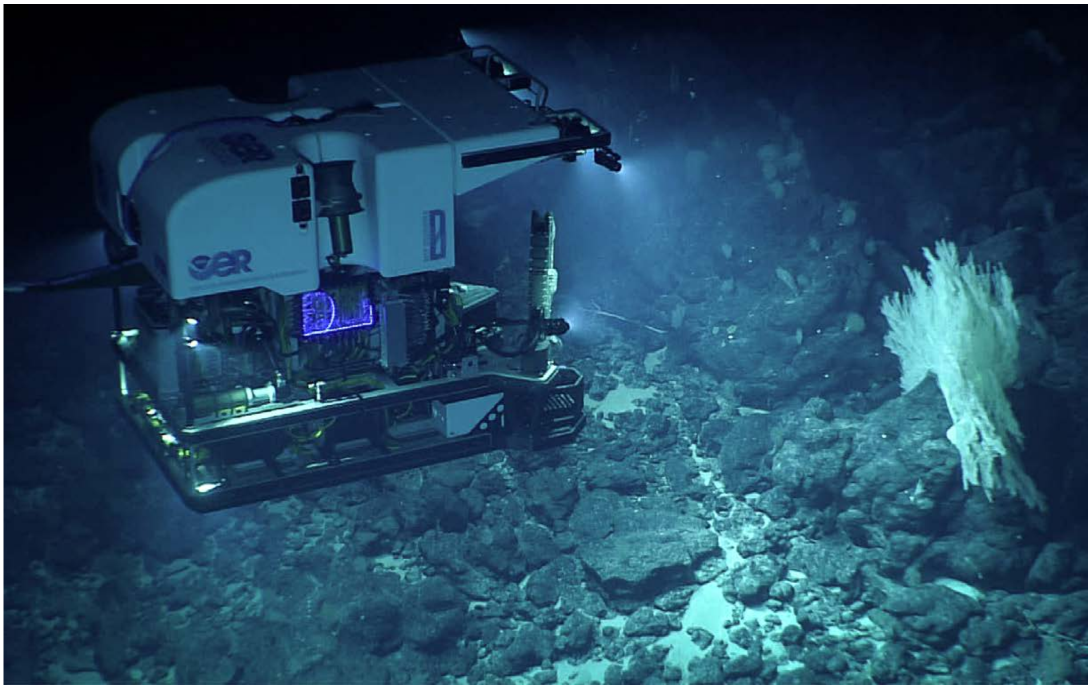
In June 2020, the White House Ocean Policy Committee released a new national strategy to map, explore, and characterize the US Exclusive Economic Zone (EEZ) that recognizes the increasing importance of the ocean to national economic, security, and environmental interests—the so-called "blue economy." As the only federal program dedicated to ocean exploration, OER is critical to the successful implementation of the new *National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone* (NOMEC, 2020) developed by the National

NOAA Ship *Okeanos Explorer* is the only federal vessel dedicated to exploring our largely unknown ocean for the purpose of discovery and the advancement of knowledge about the deep ocean. *Image credit: Art Howard/GFOE*



ABOVE. The ROV *Deep Discoverer* suction sampler acquires a squat lobster at ~722 m (2,369 ft) depth during the Windows to the Deep expedition.

RIGHT. *Deep Discoverer* documents the benthic communities at Paganini Seamount during the Deep-Sea Symphony: Exploring the Musicians Seamounts expedition.



Ocean Mapping, Exploration, and Characterization Council. This blueprint for the future includes developing and using new and emerging science and technologies and collaborating and coordinating among federal agencies and with state governments, private industry, academia, and nongovernmental organizations. The strategy calls for the establishment of common protocols to make data usable and widely available. In addition, it directs federal agencies to inspire and involve the public by supporting ocean science and technology outreach and education.

At the same time, OER responded to pandemic limitations by adapting its workforce strategies so that the goals set out by NOMEC could be met. Scientists and staff found new ways to work and share research together virtually, while planning for an eventual return to ship operations. OER is also developing new methods to characterize the ocean via advanced telepresence, data collection and storage, and dissemination that not only will advance our understanding of the marine environment, but also open new commercial opportunities to support the blue economy. This section of the Ocean Exploration Supplement highlights some of these advances and reviews NOAA's current progress toward achieving the NOMEC goals.

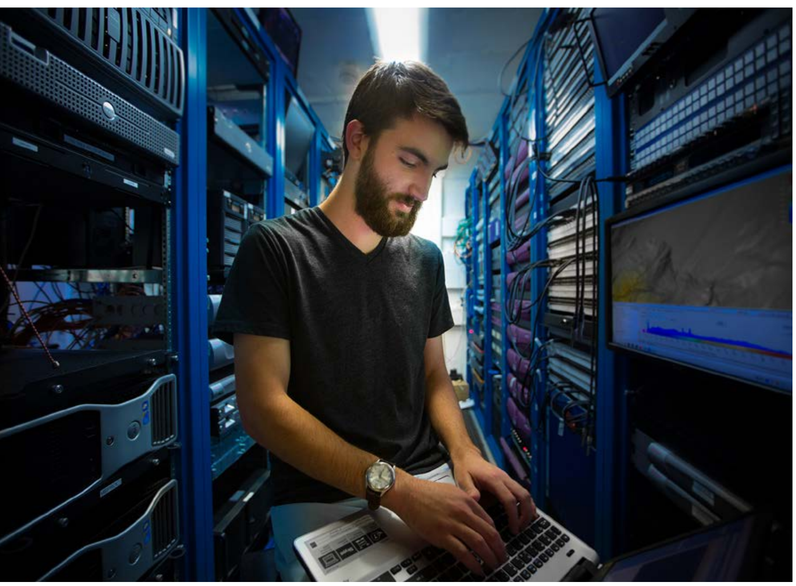
Harnessing the Blue Economy by Expanding Ocean Exploration

One underlying objective of NOMEC is to expand the US blue economy by sustainably using ocean resources to benefit all sectors of society. To accomplish this goal, NOAA is accelerating its support of cutting-edge science and technology research; strengthening collaborations with public-private partners; and developing transformative technologies, such as unmanned systems, artificial intelligence, 'omics, and the cloud.

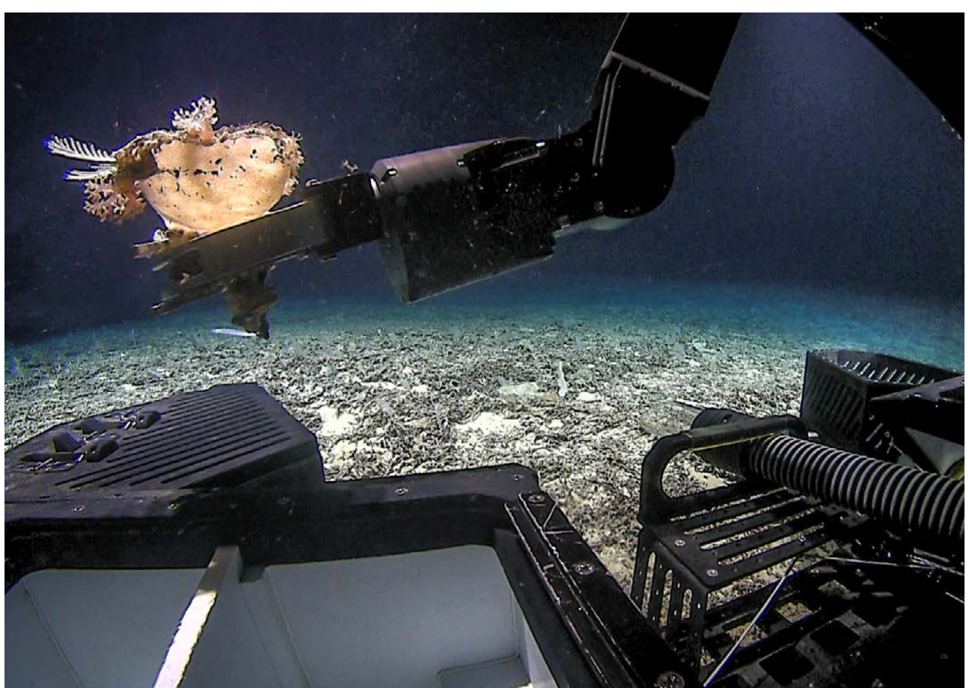
The health and resilience of the ocean is critical to the blue economy. A robust blue economy enhances the nation's leadership and competitiveness by strengthening national, economic, food, energy, and environmental security. OER and its partners are moving forward to accomplish NOAA's goal of doubling the US blue economy by 2030 through:

- Expanding ocean exploration to make seafloor maps and characterization data for the entire US Exclusive Economic Zone available to support decisions about stewardship of ocean resources, whether for conservation and protection or identification of energy sources, minerals, and pharmaceuticals vital to US industries, human health, and national security.
- Informing traditional and renewable energy siting and evaluating the availability of critical minerals resources.
- Assessing populations and habitats of managed marine species.
- Driving innovation of novel technologies and inspiring and educating the next generation of STEM (science, technology, engineering, and mathematics) professionals.

In June 2020, the Ocean Exploration Advisory Board's Subcommittee on the Blue Economy provided recommendations for NOAA's role in the blue economy, and an internal agency committee developed a new Blue Economy Strategic Plan (https://oceanservice.noaa.gov/economy/) based on those recommendations and NOAA goals. Despite the postponement of NOAA Ship *Okeanos Explorer* at-sea operations in 2020, several projects funded through OER's competitive grants program (https://oceanexplorer.noaa.gov/about/funding-opps/ffo-recipients.html) and tied to the blue economy were executed.



ABOVE. Data management intern Dan Bolan working in the rack room, the computer system hub for NOAA Ship *Okeanos Explorer.*



RIGHT. Pilots on board NOAA Ship *Okeanos Explorer* guide ROV *Deep Discoverer*'s manipulator arms to grab a sample of a sponge (Porifera) and its associates during the 2019 Southeastern US Deep-Sea Exploration expedition.

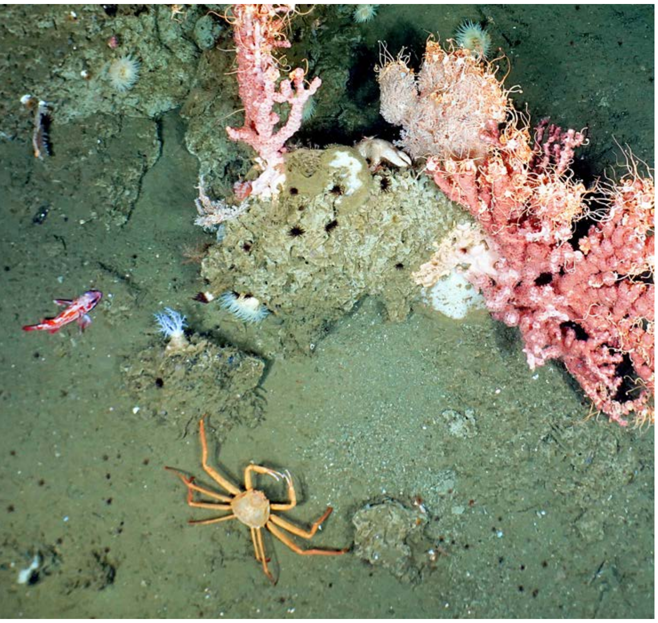
BIOPROSPECTING IN AN ANCIENT SUBMARINE FOREST

https://oceanexplorer.noaa.gov/explorations/20ancient-forest/

Scientists from Northeastern University and the University of Utah, funded by OER, explored the biodiversity and economic potential of a submerged forest off the Alabama coast, which provides an unusually large, biodiverse, and temporally stable wood-associated marine habitat. Marine animals and associated symbiotic microorganisms that live on and in submerged wood have recently been shown to be a potentially rich source for biomolecules of high biopharmaceutical and biotechnological value, including a compound under investigation for antiparasitic properties.

RIGHT. Ocean Genome Legacy Center Director Dan Distel, Dive Safety Officer Grant Lockridge, and researcher Francis Choi wrap a 60,000-year-old log to keep it damp for the trip back to shore where it will be dissected to discover what marine species were living inside. *Image credit: Brian Helmuth*

RIGHT. Dan Distel carefully removes a shipworm from its burrow in wood collected in the Alabama underwater forest. Sometimes called "termites of the sea," shipworms bore into submerged wood, eating the cellulose of the wood and creating burrows. The overall biopharmaceutical potential of the bacteria in shipworms is high. *Video credit: Brian Helmuth*

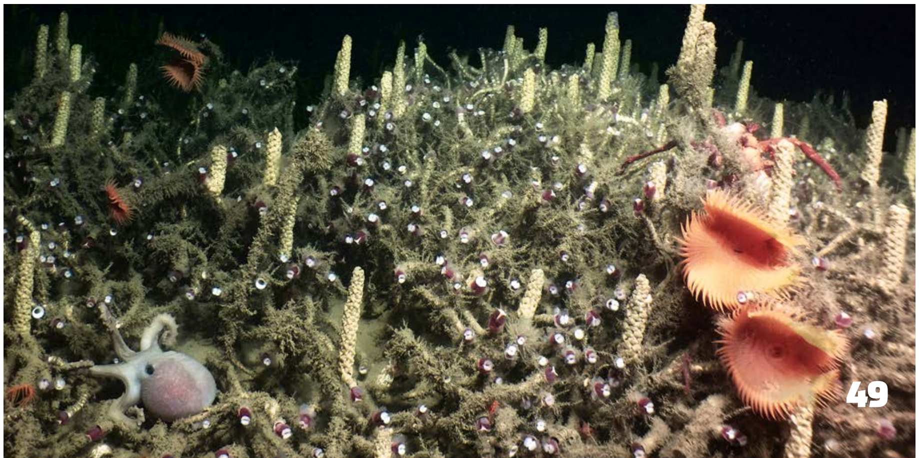


STUDYING THE DEEP SEA'S METHANE SEEPS

https://oceanexplorer.noaa.gov/explorations/20cascadia-seeps/

A team from Oregon State University, in partnership with the Ocean Exploration Trust and its exploration vessel *Nautilus*, studied methane seeps off the northwest Pacific coast, how they interact with ocean systems, and how that interaction may support a blue economy future (pages 32–33). There is increasing evidence that methane seeps act as key habitats where microbes harness the leaking greenhouse gas methane as a source of food for a diversity of organisms, including commercially harvested species. Large tubeworms, microbially created carbonate boulders and pavements, and even frozen methane create structure within an otherwise flat muddy landscape. This diversity in physical habitats then leads to animal and microbial diversity. As part of the cruise in September 2020, the team quantified the footprint of several seeps and examined what species are present at seeps. Ultimately, the data collected will provide better information for managers who regulate these regions for fishing and other extractive resources.

ABOVE AND RIGHT. Examples of the diversity of habitats and fauna at methane seeps along the Cascadia margin, northeast Pacific Ocean. *Image credit: Ocean Exploration Trust/Nautilus Live*



DEVELOPING A LONG-DURATION SENSOR PLATFORM

OER's competitive grants program is funding development of a long-duration sensor platform that can measure ocean currents and also detect and identify animals in the water column. A team from the University of Washington will be equipping autonomous underwater gliders in Juan de Fuca Canyon off the coast of Washington state with acoustic Doppler current profilers (ADCPs). These instruments are most often used to measure the speed and direction of ocean currents, but they can also be used to detect and quantify animals as they move through the water column. In 2021, the team will demonstrate how ADCPs can be used to simultaneously collect needed physical and biological data in a manner that is easier and cheaper than current ship-based efforts. By providing a more complete picture of the ecosystem, these new technologies and processes will better enable resource managers to make policy decisions that support sustainable resource management.

Seagliders like the one shown here will play a central role in an OER-funded project utilizing acoustic Doppler current profilers. *Image credit: Applied Physics Laboratory, University of Washington*

ARCHAEOLOGICAL HIGHLIGHT: WIMBLE SHOALS

https://oceanexplorer.noaa.gov/explorations/20wimble-shoals/

A team of researchers led by NOAA's Office of National Marine Sanctuaries partnered with the National Centers for Coastal and Ocean Science and the East Carolina University Program in Maritime Studies explored Wimble Shoals off the North Carolina coast on Duke University's research vessel *Shearwat*er. The team was seeking to characterize the maritime heritage resources of Wimble Shoals in order to enhance our knowledge of coastal processes affecting shipwrecks and the marine ecosystem off Hatteras Island. Wimble Shoals is a potential hazard adjacent to a major shipping route. Thus, it is likely that hundreds of catastrophic maritime events have occurred within the vicinity of Wimble Shoals over the past 400 years, making the Shoals a rich reserve of underwater cultural heritage.

ABOVE. Launched in 1888, *Governor Ames* was the first five-masted schooner on the eastern seaboard. It has an interesting career that took it to the Atlantic, Gulf of Mexico, and even the Pacific, until it sank on December 13, 1909. *Image credit: Library of Congress*

RIGHT. A German torpedo struck the British Tanker SS *Mirlo* in August 16, 1918. *Image credit: Austin Dwyer*

Exploring and Characterizing the Ocean

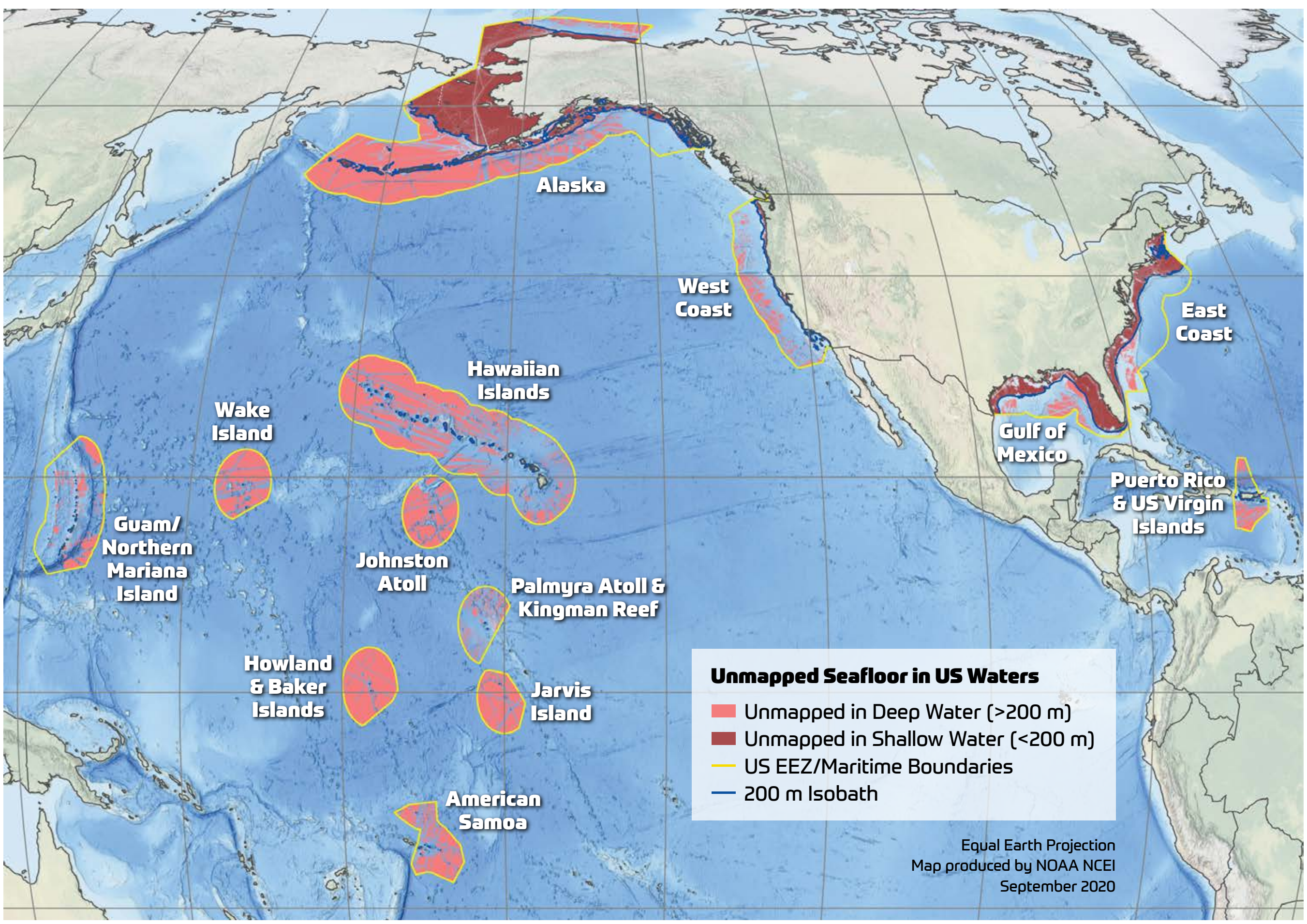
As 2020 field season activities for NOAA Ship *Okeanos Explorer* were postponed, scientists, technicians, educators, and researchers who support the vessel and its capabilities began planning for future seagoing missions. Future exploration will include the Mid-Atlantic Ridge in 2022, whose hydrothermal vent fields and seamounts are of great interest to resource managers and scientists as they try to understand the connectivity of sensitive marine habitats across the Atlantic Ocean.

OER expanded its mission of ocean exploration and characterization in support of the blue economy in a variety of ways. New and existing agreements with academic and commercial partners allowed some NOAA-sponsored mapping and scientific cruises to proceed. New seagoing and data-collection technologies were tested, and other efforts focused on building out infrastructure to better prepare for new advancements and operations in support of the national program.

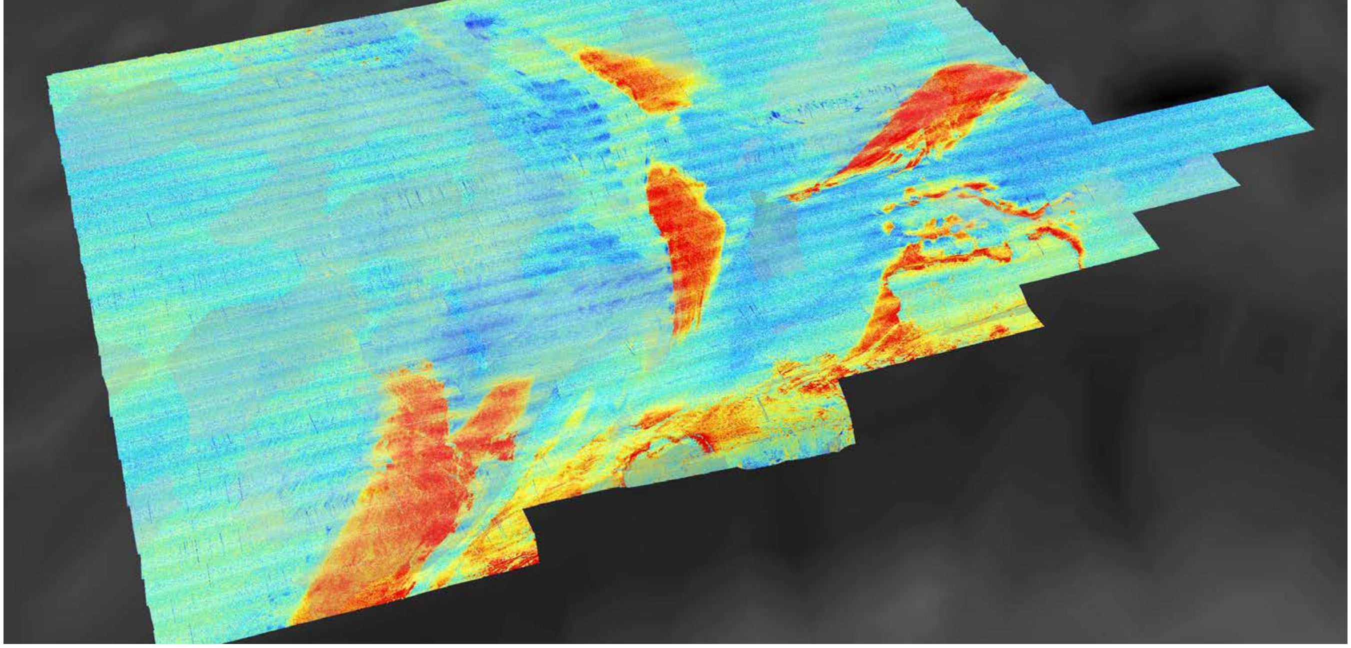
DEEPWATER MAPPING MANUAL

The shift to a virtual work model also allowed OER personnel to produce the new *NOAA OER Deepwater Exploration Mapping Procedures Manual* (Hoy et al., 2020). This first-of-its-kind manual is now being used by internal and external partners, including the crew aboard R/V *OceanXplorer* operated by the OceanX Exploration Initiative, who are using this manual to guide and develop their deepwater mapping procedures. The manual describes OER's principles and procedures for deep water (>200 m) acoustic mapping and supports the *National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone* (NOMEC, 2020). In particular, this manual is being used to help build out national standards for ocean mapping as part of one of NOMEC's goals for Fiscal Year 2021.

The manual also sets several principles for operators to follow, including (1) always collect data during transit periods, (2) maximize coverage in areas where data have



Unmapped seafloor in US waters, categorized by deep (>200 m) and shallow (<200 m) water. The map displays data from the August 2020 version of the US Bathymetry Gap Analysis (Westington et al., 2018), which is updated twice per year. As of September 2020, 52% of the US seafloor at >200 m depth has been mapped. *Image credit: US Bathymetry Gap Analysis and NCEI.*



Multibeam backscatter data draped on bathymetry from the southern portion of the Blake Plateau survey. Warm colors are high-intensity backscatter anomalies that show where the seafloor is hard and/or coarse. Low backscatter (cool colors) shows where the seafloor is soft and/or smooth. Coral mounds, exposed carbonate, and sand drifts can be interpreted from these high backscatter anomalies. *Image credit: Fugro*

not been collected previously, (3) collect useful and quality data by performing annual calibrations, (4) apply correctors for deepwater environments (such as sound speed), (5) maximize sounding density and minimize interference, and (6) produce useful data products that can be used with non-proprietary software. The manual is intended to help ensure that the value of all ocean exploration community contributions is maximized in pursuit of national objectives.

EXPLORER MODEL FOR SCIENTIFIC AND PUBLIC COLLABORATION

OER submitted an essay in the 2020 issue of the *Journal of Ocean Technology* reviewing accomplishments of OER's "Explorer Model" of expedition planning, mission operations, and outreach. Cantwell et al. (2020) describe a collaborative approach to priority identification, strategic partnerships, pooling of resources, open and free access to data, and continuous engagement of stakeholders. While OER has used and refined the Explorer Model for the past decade aboard *Okeanos Explorer*, this is the first time the operational paradigm has been documented for the benefit of the greater ocean exploration community. The hope is that others will use this essay as a guide for adopting or developing their own modes of operation that leverage OER's community-driven exploration experience.

PRIVATE INDUSTRY

This past year, OER saw the execution and completion of the first "proof-of-concept" survey by the multinational geodata company Fugro, leveraging existing hydrographic survey contract mechanisms through the NOAA Office of Coast Survey. OER and National Oceanographic Partnership Program funds were used to collect bathymetric data in support of ocean exploration. In fall 2019, the survey mapped more than 28,000 km^2 of the US EEZ on the Blake Plateau in the southeast Atlantic. This survey filled a significant gap in US EEZ coverage and advanced Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE) campaign objectives. OER and Fugro also used the survey to establish shallow and deep water reference areas the community can use to calibrate multibeam sonar systems so that backscatter data collected for habitat analysis and other purposes are consistent. All survey data were made available in the national archives (https://www.ncei.noaa.gov/archive) at the NOAA National Centers for Environmental Information in May 2020.

EXPLORATION VARIABLES

OER has finalized a strategy for identifying information needed when exploring an area for the first time. This list of data is referred to as "exploration variables" (EVs). As a leader in ocean exploration, the strategy will guide OER's data collection efforts, serve as a model for others to consider for their own exploration work, and is intended to inform the NOMEC effort. Development of the strategy for collecting EVs was accomplished by conducting a literature review of ocean exploration and observation workshop reports and white papers that outline information needed to explore and observe the deep ocean. OER then considered how it currently collects those EVs through NOAA Ship *Okeanos Explorer* operations and how the program can improve the collection of other data. OER will publish the strategy in early 2021.

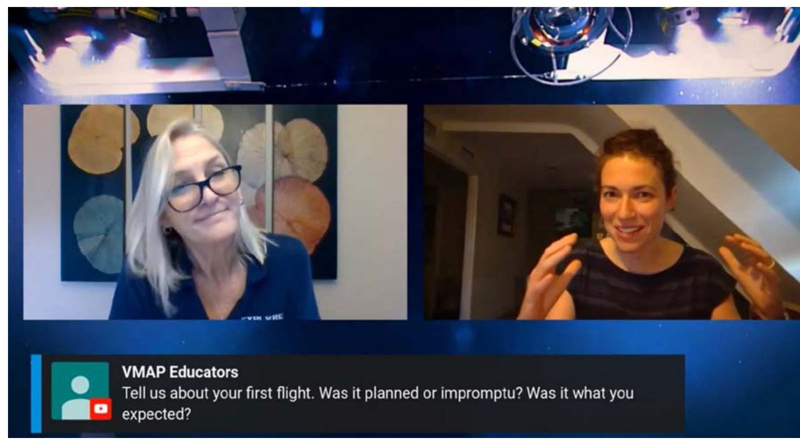
Engaging Educators and the Public with Virtual Tools

Education and outreach initiatives were created to update and expand OER's ocean exploration content for teachers and the general public. In 2020, OER planned and designed a new education website in partnership with the Schmidt Ocean Institute (SOI) and Ocean Exploration Trust (OET). OER also developed and piloted an online professional development mini-series for educators using innovative video tools in partnership with the University of Rhode Island's Inner Space Center. These efforts arose out of necessity to communicate in virtual ways, but also helped speed efforts to provide educators with fresh, relevant, and useful ocean exploration-related content already underway.

The Ocean Exploration Advisory Board conducted a review of OER's education program in 2018. As a result of the review, SOI, OET, and OER agreed that educators would be best served with a single education website that provided the "best of" ocean exploration content from all three organizations. While the three organizations will maintain their own education content on their respective websites, when the new website launches, educators will have access to "one-stop shopping" for resources and information about ocean exploration. The new website, called the Deep Ocean Exploration Project, is projected to launch in spring 2021.

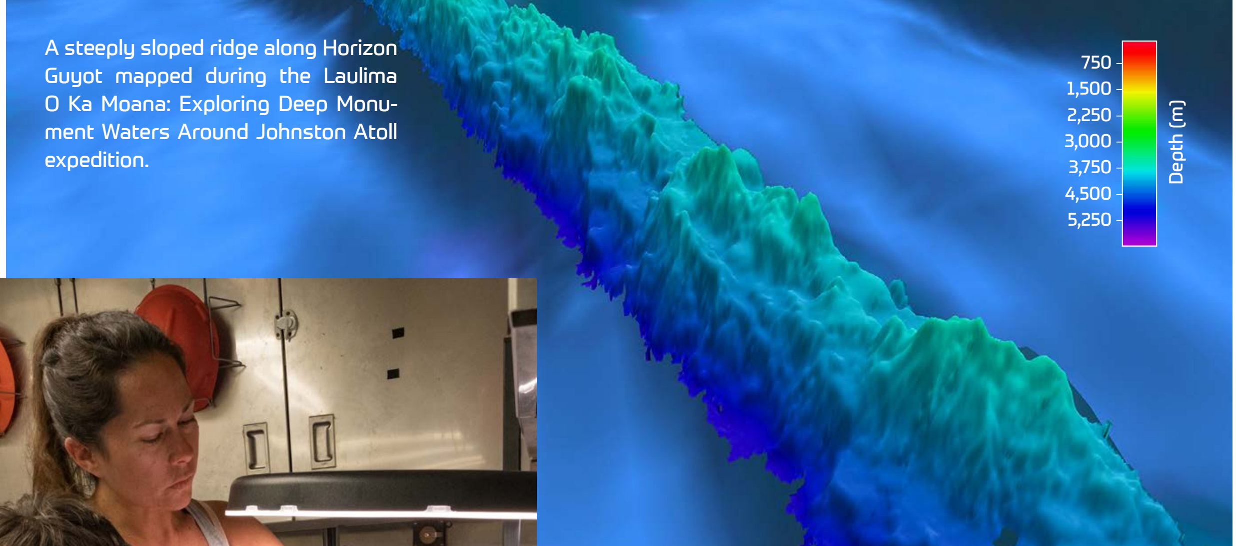
During a spring 2020 "Celebrating Our Ocean Planet" campaign, OER produced webinars that feature scientists discussing and answering questions about OER operations, including research on the water column and unexpected finds. These webinars drew more than 280 viewers during each web broadcast. As part of the campaign, OER also rebroadcast 10 previous deep ocean dives on the OER website (https://oceanexplorer.noaa.gov/), resulting in more than 29,000 public views.

BELOW. ROV Pilot Gabrielle Inglis and OER Education Program Manager Susan Haynes respond to participant questions during one of several live OER educator professional development opportunities supported by the University of Rhode Island's Inner Space Center in the fall of 2020. *Image credit: OER and Inner Space Center*



ABOVE. OER's Kasey Cantwell speaks in the museum's Ocean Explorer Theater, the backdrop for a panel discussion on samples. Collections at the museum are held in trust for research, exhibition, education, and public enjoyment and play an essential role in advancing scientific knowledge and increasing scientific literacy. Biological samples collected during *Okeanos Explorer* expeditions are accessioned to the museum and comprise the National Ocean Exploration Collection.

BELOW. A young visitor in Sant Ocean Hall watches video footage taken by ROV *Deep Discoverer* during "Secrets of the Seas Revealed," a public program supported by OER and the NOAA National Systematics Laboratory at the National Museum of Natural History. Visitors learned about the often untold story of what happens to the biological and geological samples collected during an ocean expedition after the ship returns to shore. *Image credit: Anna Lienesch, NOAA NESDIS/NCEI Affiliate*



A steeply sloped ridge along Horizon Guyot mapped during the Laulima O Ka Moana: Exploring Deep Monument Waters Around Johnston Atoll expedition.

NOAA Educational Partnership Program (EPP) Intern Nikola Rodriguez and Matt Dornback, then with the National Centers for Environmental Information, process biological specimens collected during an ROV dive.

Onboard science lead Chris Kelley and Nikola Rodriguez discuss and take a closer look at deepwater habitats explored with ROV *Deep Discoverer* on Horizon Guyot. On the cruise, Nikola logged scientific observations during ROV dives and analyzed these annotations for a final project.

As it was not possible to hold the in-person educator professional development workshops OER would normally offer in partnership with its Education Alliance Partners (https://oceanexplorer.noaa.gov/edu/alliances/welcome.html)—a network of aquaria and other informal learning centers—OER developed a new virtual workshop approach to meet educator needs. Taking advantage of the opportunity to redesign the professional development concept, rather than an extensive eight-hour event held on a weekend, OER offered a three-part online event that introduced entirely new content and allowed teachers to participate in a sequence of short events.

As part of the revised virtual professional development workshops, OER produced a series of videos titled "Deep Sea Dialogues" that combined conversations with leading ocean scientists and underwater content produced by the University of Rhode Island's Inner Space Center (https://oceanexplorer.noaa.gov/edu/multimedia-resources/dsd/dsd.html). Teachers viewed the short introductory video at home, joined other teachers in a live broadcast hosted by a local science institution or aquarium that featured question-and-answer discussions with ocean exploration experts, and then participated in a follow-up session with their local peers. During the fall 2020 session, more than 280 educators took part in the live sessions. The first Deep Sea Dialogue professional development workshop focused on underwater robotics. Subsequent programs are being planned for hydrothermal vents and deep-sea mapping.

In 2021, OER will expand its "Explorer-in-Training" program. The program has enabled the next generation of ocean explorers to gain valuable experience in deepwater mapping and exploration. It will now include opportunities in science, technology, and communications for undergraduates and graduate students.

In summary, OER's engagement efforts in the challenging year of 2020 have supported NOMEC's goal to inspire and involve the public by communicating the importance of ocean science and technology. They also demonstrated the potential for careers in STEM so that a STEM and ocean-literate workforce will be able to support job growth in many ocean sectors.

OER Partnerships Lead to New Exploration Technologies

Many of OER's new and existing partnerships bore fruit in 2020, all of which will advance NOMEC goals. For example, in May 2019, NOAA Research established a new cooperative institute dedicated to ocean exploration at the University of Rhode Island. Partners of the new Ocean Exploration Cooperative Institute (OECI) include the University of New Hampshire, the University of Southern Mississippi, the Woods Hole Oceanographic Institution, and the Ocean Exploration Trust. This consortium received an initial five-year award of up to $94 million. The mission of the OECI is threefold:

1. To explore the 3 billion acres of submerged US ocean territory in order to strengthen the nation's blue economy, aid responsible management, and promote greater scientific understanding of the nation's vast underwater territory, known as the exclusive economic zone.
2. To develop the technology needed to carry out this effort, including the greater use of autonomous vehicle systems operating from a broad range of seagoing platforms that explore the entire water column.
3. To educate the next generation of scientists, engineers, and educators needed to maintain our nation's leading role in STEM-related professions and growing workforce.

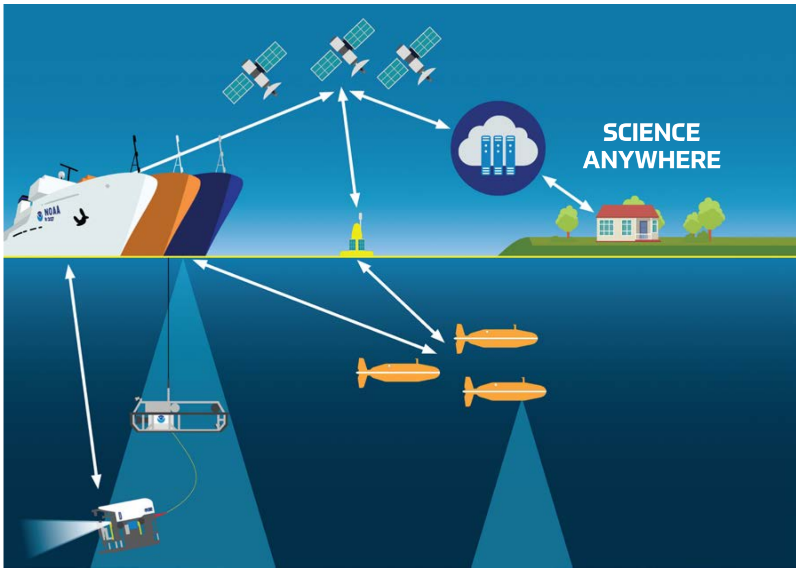
In 2020, the OECI partnership matured as institutions conducted expeditions, research and development, and other activities to advance ocean exploration when federal operations were curtailed. The OECI leverages the capabilities of the institutions involved to accelerate the pace of ocean exploration and technology development in pursuit of NOMEC objectives.

TELEPRESENCE

As the demand grows for more data from the ocean—whether seafloor mapping for potential mineral resources, water column data for climate and weather prediction models, or biological characterization to inform fisheries management—so too has the need to work with partners to develop the tools to collect, assemble, and analyze these data. While the deployment of seagoing research vessels as platforms for ocean exploration will continue, the use of uncrewed and autonomous systems—in tandem with new forms of telepresence, sensors, and artificial intelligence—will open large areas of the ocean, often at lower cost and with increased safety and reduced risk, especially in remote or extreme environments.

To capitalize on new commercial communications technologies like low-latency and high-bandwidth networks that offer two-way communications and advances in video transmission technologies, OER developed the "Telepresence 2.0" concept that uses these advances to create a cost-efficient, flexible, and adaptable architecture for telepresence operations. Deploying this architecture will allow innovations in how OER and the ocean exploration community use telepresence for science and public engagement. It will also make it possible to test and operate ship-based vehicles from shore and to control shipboard systems remotely. OER is working with OECI partner the University of Rhode Island's Inner Space Center to test Telepresence 2.0 infrastructure.

To socialize the concept, OER collaborated with academic partners to publish "The Future of Telepresence" (Kennedy et al., 2020) in *The Journal of Ocean Technology*. The article summarizes recent advances and describes how Telepresence 2.0 will serve as a bridge to a "Telepresence X.0" future where ocean exploration data are streamed to cloud-based servers for processing and distribution in real time using new low-Earth orbit satellite systems.



The future of telepresence involves a flexible architecture where any ship of exploration, autonomous vehicle, or relevant observational network can transmit high volumes of full resolution data to low-Earth orbit satellites and to the Cloud. Data products, including guidance for expeditions underway, can be processed in near-real time using cloud/edge computing services. Scientists can participate from any location, limited only by local Internet speeds.

OER awarded a three-year grant through the National Oceanographic Partnership Program to support development of the Saildrone Surveyor, a 22 m (72 ft) uncrewed surface vehicle powered exclusively by wind for forward propulsion and solar to run onboard instruments, that will collect detailed bathymetric and water column data and transmit the data back to shore in real time. This vehicle is expected to be deployed in spring 2021. *Image credit: Saildrone*

REMOTE MAPPING BY SAIL

Seafloor mapping has come a long way since the days of launching a pail of rocks over the side of a vessel to measure ocean depth. Sonar technology has become an invaluable tool for illuminating deep-sea features. Understanding these features is important to navigating permitting for minerals and energy development, as well as for preserving biological habitats and archaeological resources. The next step in developing seafloor mapping capabilities is combining remote uncrewed platforms with sonar abilities so that the mapping goals of the NOMEC blue economy strategy can be accomplished more quickly at lower cost.

OER has set an ambitious goal to increase the operational usage of unmanned systems by 40% over the next five years in support of ocean exploration. To accomplish that goal, OER is looking toward new platforms, such as the Saildrone (https://www.saildrone.com/) uncrewed surface vehicle that can conduct long-duration mapping expeditions and transmit data back to shore in real time. Saildrone vehicles and systems are powered entirely by wind and solar power. A fleet of 7 m-long Saildrones completed a coastal bathymetry and mapping mission just offshore of the North Slope of Alaska in May 2020 for NOAA, demonstrating the value of such technology for bathymetric data collection.

Through the National Oceanographic Partnership Program (NOPP), OER awarded a three-year grant to the University of New Hampshire, Saildrone Inc., and the Monterey Bay Aquarium Research Institute to test and integrate acoustic and other sensors into a new much bigger platform, the Saildrone Surveyor, a 22 m uncrewed surface vessel designed to collect detailed mapping data of the seafloor and water column that can be transmitted back to shore in real time, allowing for identification of exploration targets of interest. The Saildrone Surveyor will also be equipped with environmental sensors to support studies looking at harmful algal blooms, microbial ecology, water quality, and environmental DNA indicative of invasive species and larger animals. The Saildrone Surveyor is currently undergoing sea trials and is expected to be operational in 2021.

AUTONOMOUS VESSELS

As part of the OECI, and to further accomplish mapping and ocean exploration goals using remote technologies, the University of New Hampshire signed a contract in November 2020 with iXblue, a France-based maritime technology firm, to procure a DriX autonomous surface vessel and a custom-designed universal deployment system that can launch and recover both the DriX as well as autonomous underwater vehicles (AUVs). The two-in-one system will effectively operate as an oceangoing launchpad for autonomous systems to explore the undersea world. The University of New Hampshire will operate the new DriX.

To explore the deepest parts of the ocean, a region known as the hadal zone that extends from 6,000 m to 11,000 m below the sea surface, the Woods Hole Oceanographic Institution (WHOI) is developing an AUV called *Orpheus,* named for the Greek hero who made it to the underworld and back. *Orpheus* is designed to withstand the pressure of the ocean's greatest depths while working independently or as a networked "swarm" to survey and sample almost anywhere in the global ocean. The lightweight, modular design of *Orpheus* minimizes construction and shipping costs and permits the AUV to be launched from small research vessels as well as ships of opportunity. Four fixed-directional thrusters and a compact shape make *Orpheus* nimble and controllable, allowing the vehicle to

Ocean Exploration Cooperative Institute partner UNH recently signed a purchase contract to acquire a DriX autonomous surface vessel from the high-tech company iXblue. *Image credit: Alex De Robertis/NOAA Fisheries* maneuver around obstacles, land on the seafloor to collect samples, and lift off again to continue its mission. OER is working with WHOI to provide shiptime and cruise support for continued development and testing. If proven successful, *Orpheus* could provide a relatively low cost option to explore the ocean's largely unknown hadal zone.

In the Gulf of Mexico, two vehicles from the University of Southern Mississippi are being deployed to expand the goals of NOMEC to map the US EEZ. *Eagle Ray*, a torpedo-shaped AUV with a depth rating of 2,200 m, typically performs multibeam surveys at 50 m to 15 m above the seafloor. This AUV has both wet and dry payload space, partially occupied by a Kongsberg EM 2000 multibeam sonar, a Sea-Bird CTD, and a GeoAcoustics polarity preserving sub-bottom profiler. *Mola Mola*, a smaller, slower, and more maneuverable hovering AUV, operates 3 m off the seafloor and collects digital photographs using a vertically oriented camera and an LED illumination system. Used together, these AUVs provide high-resolution bathymetry, sub-bottom sediment structure, and very high-resolution photographic images of specific areas of high interest. OER is funding additional sensor development and integration to be followed by expeditions to test the new technologies and operational approaches using all of these autonomous platforms.

OER partnerships with academic institutions and industry are pushing the boundaries of ocean exploration despite the many challenges of the past year.

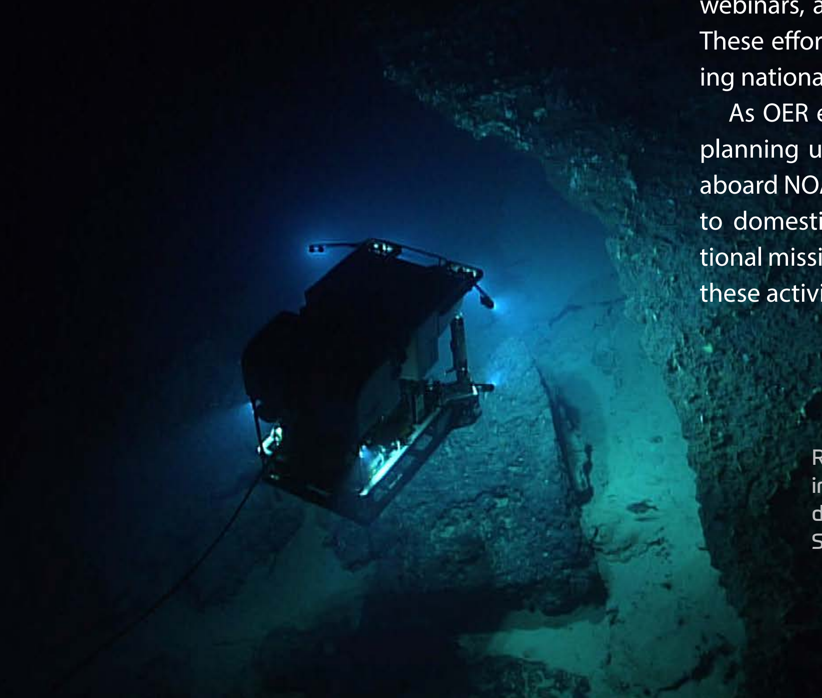
Overcoming Challenges While Looking Ahead to 2021

During 2020, NOAA OER overcame many challenges by tapping the creativity of its people and by relying on the strength of its existing institutional partnerships. These partnerships are leading to a new world of ocean exploration that is faster, cheaper, and better, while supporting key NOAA, national, and international goals to better understand and manage the ocean and its resources.

The release of the new *National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone* (NOMEC, 2020) in June 2020 provided a framework for the future in support of the blue economy. It was followed by the NOMEC implementation plan in January 2021.

While personnel were required to work at home during much of 2020 as a result of coronavirus pandemic restrictions, OER advanced virtual work models and technological autonomy. OER personnel also improved existing processes for primary observation data collection and released a new deepwater procedures manual to make it easier for others to explore and contribute to national ocean exploration results. Outreach and education efforts found new ways to reach educators and the public, including implementing a virtual professional development program and an education website with content from NOAA, the Schmidt Ocean Institute, and the Ocean Exploration Trust. OER also engaged the public with online content, ocean exploration webinars, and rebroadcasts of previous deep ocean dives. These efforts resulted in significant progress toward meeting national ocean exploration priorities in 2020.

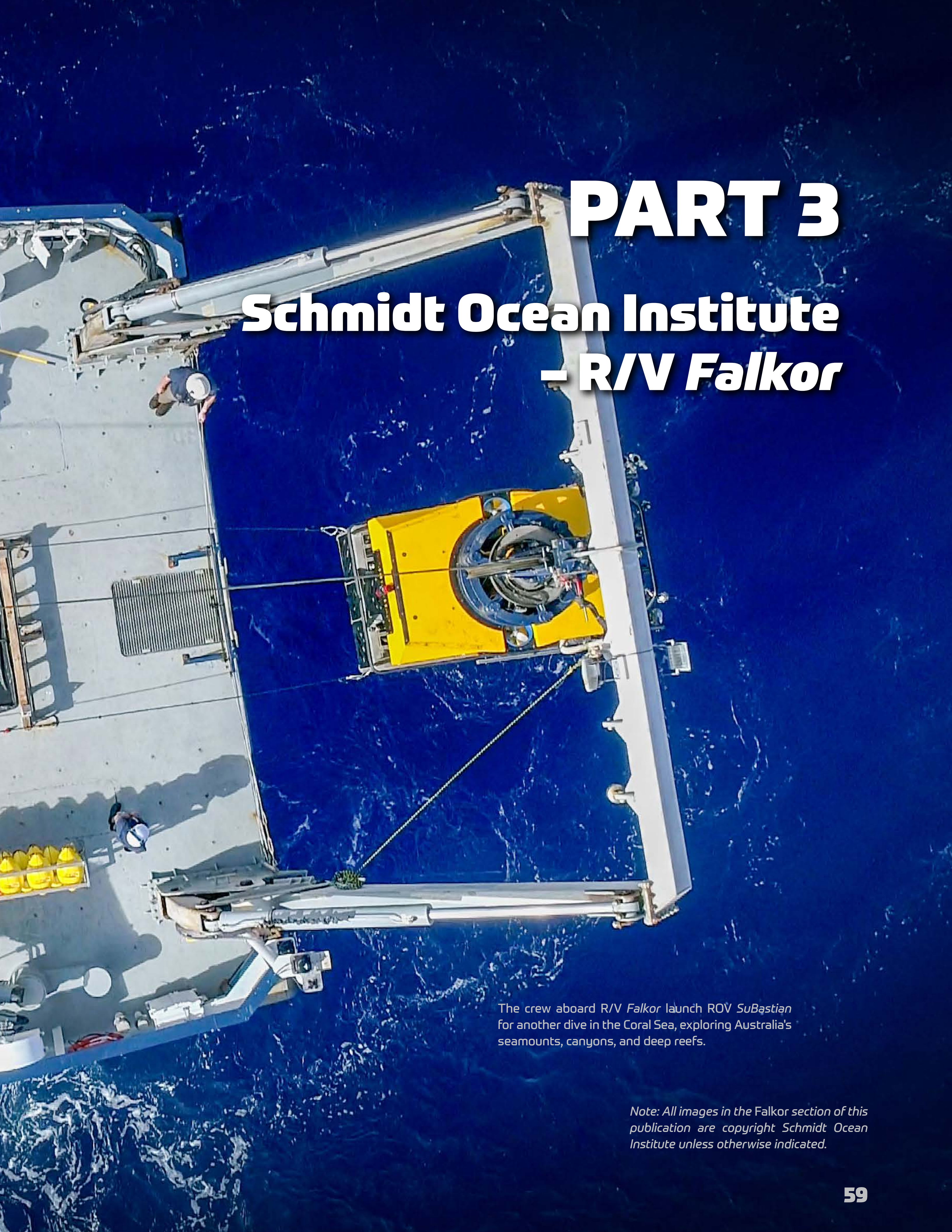
As OER expands agreements with its partners, it is also planning upcoming science, ROV, and mapping activities aboard NOAA Ship *Okeanos Explorer*, including expeditions to domestic locations on the Blake Plateau and international missions to the Corner Rise Seamounts. Details about these activities are expected to be finalized in early 2021.



ROV *Deep Discoverer* explores interesting geology on the Pourtalès Terrace during the 2019 Southeastern US Deep-Sea Exploration expedition.

PART 3

Schmidt Ocean Institute – R/V *Falkor*



The crew aboard R/V *Falkor* launch ROV *SuBastian* for another dive in the Coral Sea, exploring Australia's seamounts, canyons, and deep reefs.

Note: All images in the Falkor *section of this publication are copyright Schmidt Ocean Institute unless otherwise indicated.*

R/V *Falkor* holds position on the outside of Ribbon Reef as ROV *SuBastian* works its way up the shelf to reveal for the first time the origins of the Great Barrier Reef.

Exploration Down Under

The Schmidt Ocean Institute 2020 Field Season

By Carlie Wiener and Amara Davis

Schmidt Ocean Institute (SOI) embarked on a year-long initiative in 2020 to illuminate the deep sea around the Australian continent, facilitating important science and exploration with its research vessel *Falkor*. Even during the global pandemic, technology permitted SOI to continue with its field operations and allow for its first all-remote expedition. These expeditions led to the discovery of more than 40 potential new species and several new geologic features, as well as mapping of more than 180,000 km^2 of seafloor. The data collected will be used for future marine management decisions regarding Australia's vast marine estate, and many scientists will be answering questions with this information for years to come. This section highlights some of these important findings.

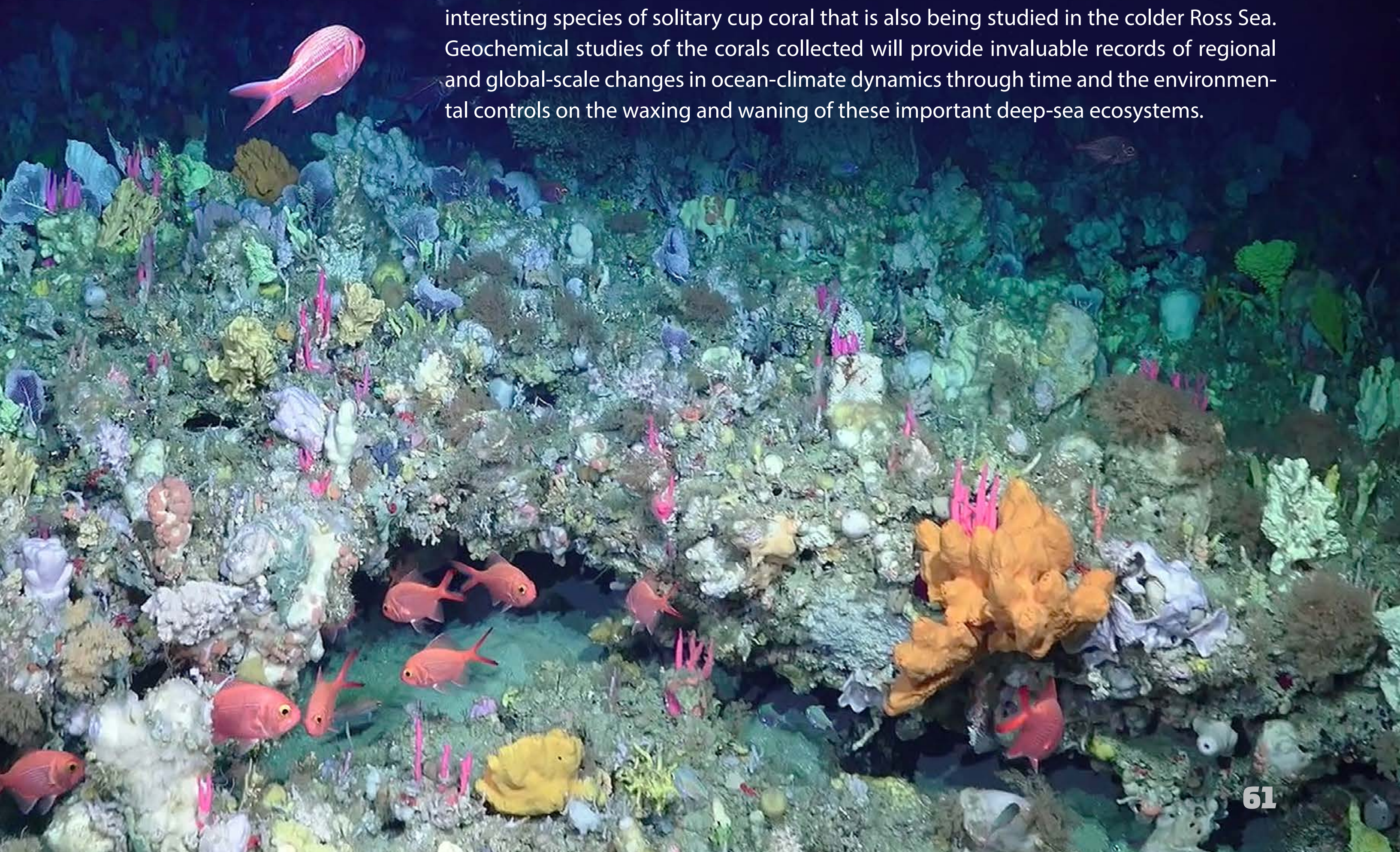
ROV *SuBastian* collects a sample from a coral graveyard.

Bremer Canyon is larger than the Grand Canyon, and multibeam maps allowed the team to safely explore it for the first time. Deep in the canyon, ledges loaded with life reveal the strong links between geology and biology in the deep ocean.

THE GREAT AUSTRALIAN DEEP-SEA CORAL AND CANYON ADVENTURE

Led by Julie Trotter, University of Western Australia, and Paolo Montagna, Consiglio Nazionale delle Ricerche

SOI partnered with the University of Western Australia to examine Australia's Bremer Canyon Marine Park, a biodiversity hotspot. Notable accomplishments of ROV dives down to 4,000 m included identification of distinct ecological zones teeming with spectacular "animal forests." These areas included coral gardens, a sponge-dominated reef, and the first natural whale fall found in Bremer Canyon. The team strategically collected samples from coral graveyards that date to the last glacial period, including a particularly interesting species of solitary cup coral that is also being studied in the colder Ross Sea. Geochemical studies of the corals collected will provide invaluable records of regional and global-scale changes in ocean-climate dynamics through time and the environmental controls on the waxing and waning of these important deep-sea ecosystems.



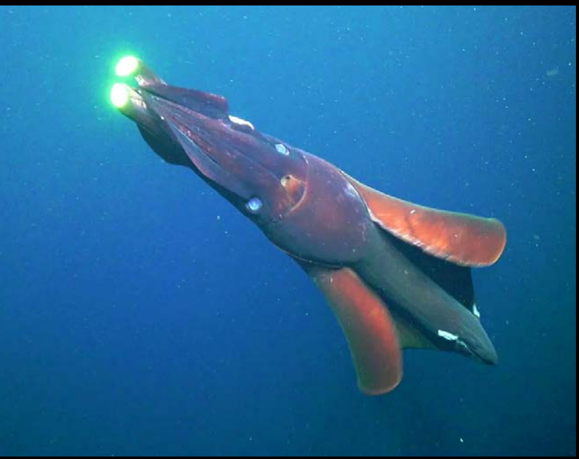
A cornucopia of pastels are found in this sponge garden.

A rare deep-sea hydroid is discovered with ROV *SuBastian* at 2,497 m depth in the Cape Range Canyon. *Branchiocerianthus* consists of a single polyp on a long stem living on a sandy bottom. It was the first time this amazing animal has been filmed and collected in Australian waters.

ILLUMINATING THE BIODIVERSITY OF THE NINGALOO CANYONS

Led by Nerida Wilson and Lisa Kirkendale, Western Australian Museum

Unique fauna of the Cape Range and Cloates Canyons documented unexplored depths featuring large communities of glass sponges and the Taning's octopus squid seen here for the first time in Western Australia. During the expedition, up to 30 potentially new underwater species were discovered. Scientists collected the first giant hydroids in Australia and observed for the first time in Western Australia numerous mollusc, barnacle, and squat lobster species. The team also found the largest specimen of the giant siphonophore *Apolemia* ever recorded and seemingly the longest sea creature ever recorded at an estimated 46 m.



A rare video capture of the Taning's octopus squid.

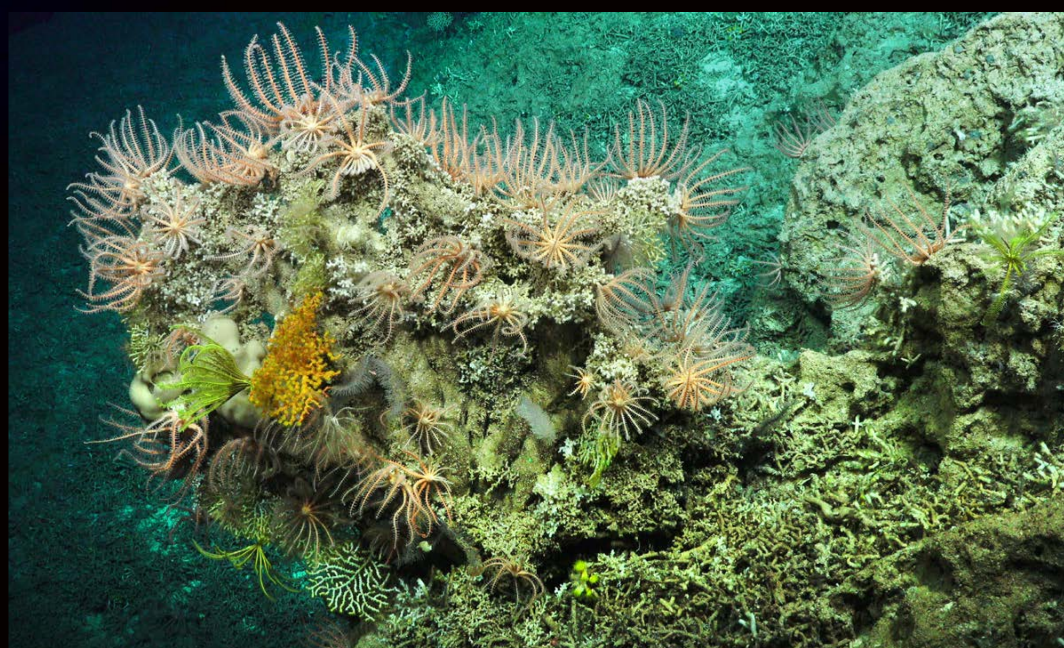
A massive, swirling siphonophore at 625 m below the surface. The team thinks this may be the longest creature discovered to date. Scientists estimated it's outer ring to be 15 m in diameter, suggesting that this section alone is 47 m in length, or about as tall as an 11-story building. They estimate the entire creature to be more than 120 m in total length.

A deep sea-squid (Chiroteuthidae) is observed at 1,000 m depth, just as the ROV *SuBastian* pilots were about to commence an ROV dive at North Horn on the northwestern tip of Osprey Reef. The team started the livestream early in an attempt to broadcast the sighting to viewers, but just missed and instead started the stream with wisps of ink as the creature sped away.

VISIONING THE CORAL SEA MARINE PARK

Led by Robin Beaman, James Cook University, in collaboration with Tom Bridge and Merrick Ekins, Queensland Museum; Brendan Brooke, Geoscience Australia; Daniela Ceccarelli and Richard Fitzpatrick, Biopixel; and Jody Webster, University of Sydney

The Great Barrier Reef is one of the most well-studied ecosystems, although the deeper reefs have been minimally explored. SOI's first expedition in the Coral Sea Marine Park, Australia's largest marine reserve and part of the larger Great Barrier Reef ecosystem, took place with scientists participating virtually due to COVID-19 restrictions. The expedition led to fish sightings where they had not been previously observed and the identification of up to 10 potentially new marine species of fish, snails, and sponges. The extraordinary mapping effort of more than 35,000 km^2 revealed 30 coral atolls, banks, submarine canyons, dune fields, submerged reefs, and landslides.



A variety of life—including crinoids, sponges, and corals—perches on exposed strata surrounded by coral skeletons near Lihou Reef in the Coral Sea Marine Park.

This is a species of deepwater spike fishes, *Hollardia goslinei*, is native to Hawai'i; however, ROV *SuBastian* captured footage of it in Australia, putting it very far from its known "home" range.

Rhinopias agroliba, an exceedingly rare species in this genus, is a new range extension record for Australia. The fish appears to "walk" along the seafloor using its pectoral fins.

Gemma Galbraith of James Cook University with one of the many coral samples collected.

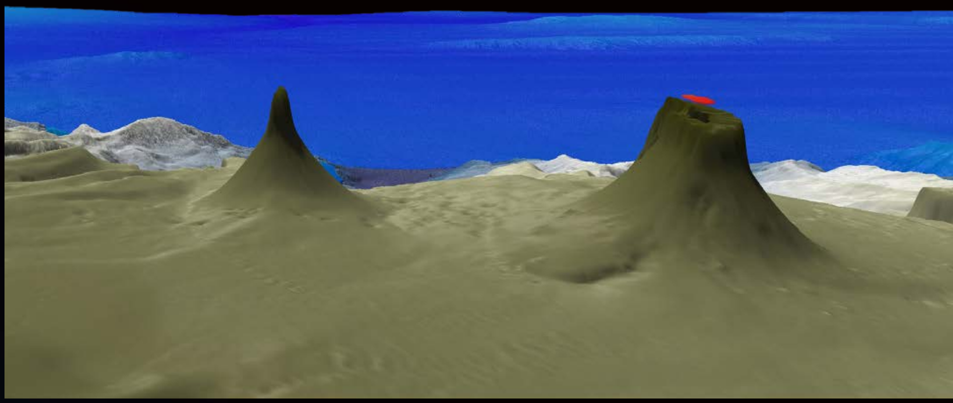
SEAMOUNTS, CANYONS, AND REEFS OF THE CORAL SEA

Led by Brendan Brooke, Geoscience Australia, in collaboration with Robin Beaman, James Cook University; Tom Bridge and Merrick Ekins, Queensland Museum; Mardi McNeil, Queensland University of Technology; Scott Nichol, Geoscience Australia; and Jody Webster, University of Sydney

A second expedition to the Coral Sea and Great Barrier Reef Marine Parks allowed scientists to view some of the deepest regions, where they discovered five undescribed species consisting of black corals and sponges, and collected habitat samples that will lead to a greater understanding of the relationship between seabed features and the animals found in the Coral Sea. The 18 live-streamed underwater dives led to the first recorded observation in Australian waters of the rare fish *Rhinopias agroliba*, a well-camouflaged ambush predator in the scorpionfish family. Additionally, the expedition collected the first ever ancient bedrock samples from the seafloor, estimated to be between 40 and 50 million years old, and the team completed the most comprehensive survey of mid-water jellyfish in the South Pacific.

The first observation of *Spirula*, also known as ram's horn squid, alive and in its natural environment. Very rarely seen or captured, they have many extinct relatives, but are the only living member of genus *Spirula*, family Spirulidae, order Spirulida.

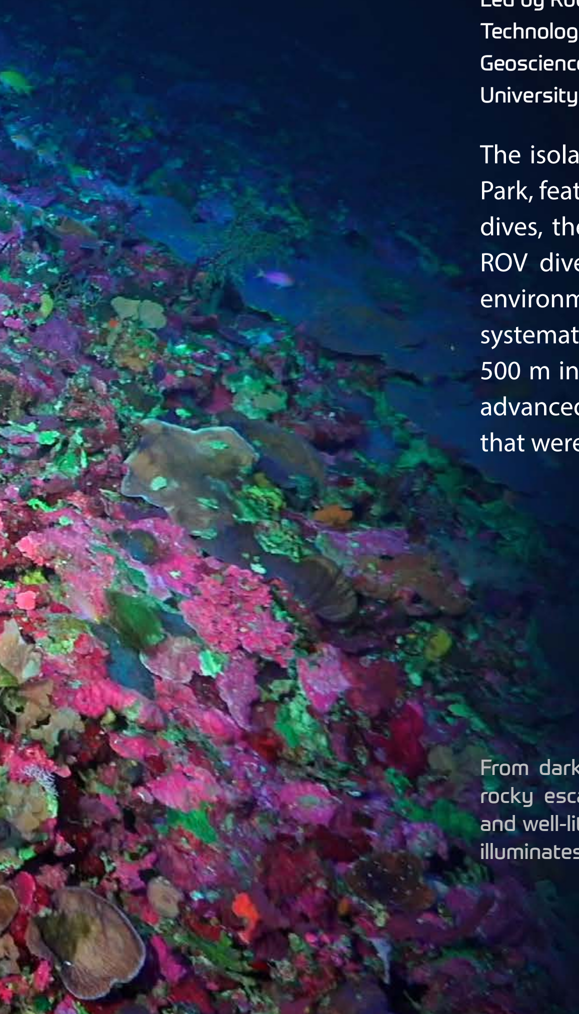
A detached reef taller than the Eiffel Tower was found in the Great Barrier Reef. After mapping the reef, a live stream of the dive was shared with the world.



NORTHERN DEPTHS OF THE GREAT BARRIER REEF

Led by Robin Beaman, James Cook University, and Mardi McNeil, Queensland University of Technology, in collaboration with Tom Bridge and Merrick Ekins, Queensland Museum; Brendan Brooke, Geoscience Australia; Daniela Ceccarelli and Richard Fitzpatrick, Biopixel; Luke Nothdurft, Queensland University of Technology; and Jody Webster, University of Sydney

The isolated Cape York Peninsula, located in the far northern Great Barrier Reef Marine Park, features complex deep-sea canyons and detached reefs. Utilizing mapping and ROV dives, the science team conducted extensive midwater surveys, recording the deepest ROV dives completed in the Great Barrier Reef and capturing the first ever natural-environment footage of a short-tail catshark and a ram's horn squid. Most notably, through systematic mapping, the team discovered a healthy, detached reef towering more than 500 m in the Great Barrier Reef. This area was last mapped 120 years ago, showing that advanced mapping technologies can reveal features of the seafloor in parts of the world that were previously thought to be well understood.



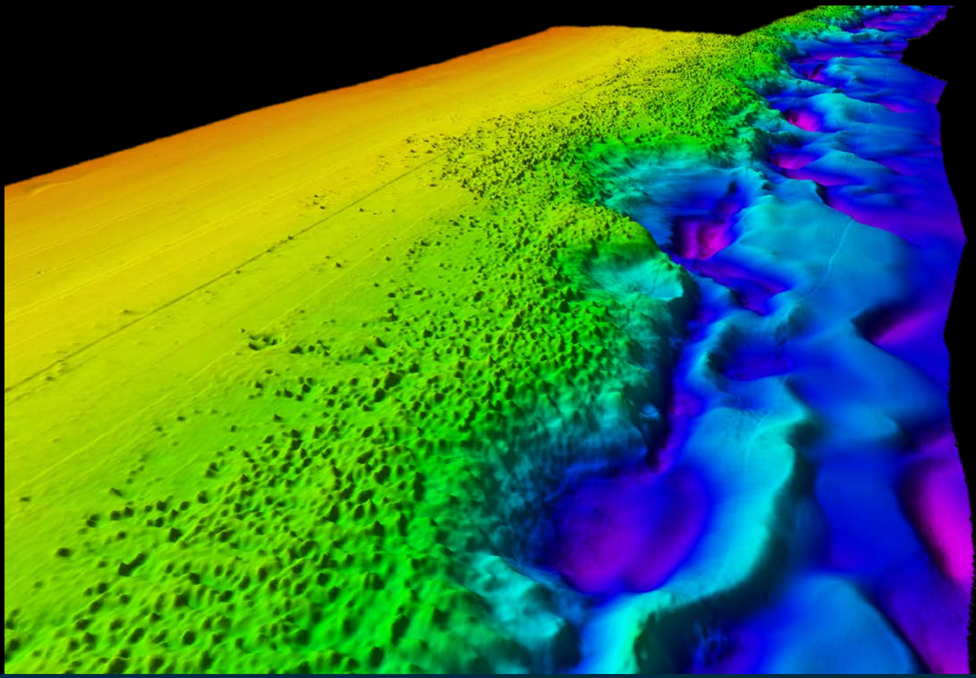
From dark sediments of the plateau floor to exposed rocky escarpments, fields of mesophotic black corals, and well-lit upper slopes and reef crest—ROV *SuBastian* illuminates a gradient of habitats in the Coral Sea.

Sediment sampling is an opportunity for the science team to look for "ooids." Ooids form over thousands of years in very shallow ocean depths and have been found along the Capricorn Channel in the Coral Sea. Finding ooids in such deep water on this expedition indicates that during the last Ice Age, the ocean was very shallow in this region, and the Australian coastline would have looked very different than it does today.

ICE AGE GEOLOGY OF THE GREAT BARRIER REEF

Led by Mardi McNeil, Queensland University of Technology, and Jody Webster, University of Sydney, in collaboration with Robin Beaman, James Cook University; Helen Bostock, University of Queensland; Kim Picard and Brendan Brooke, Geoscience Australia; and Luke Nothdurft, Queensland University of Technology

During this expedition, the science team completed systematic mapping of almost 400 km of the southern reaches of the Great Barrier Reef World Heritage Area, where the upper continental slope and shelf edge are largely unknown and poorly mapped. Once an exposed part of the Australian coastline, these features submerged as glaciers and sea level rose, flooding Australia's continental shelf. The mapping exposed a diverse array of coastal landforms, including ancient river channels and a limestone platform that may represent the 20-million-year-old base upon which the present Great Barrier Reef has grown.

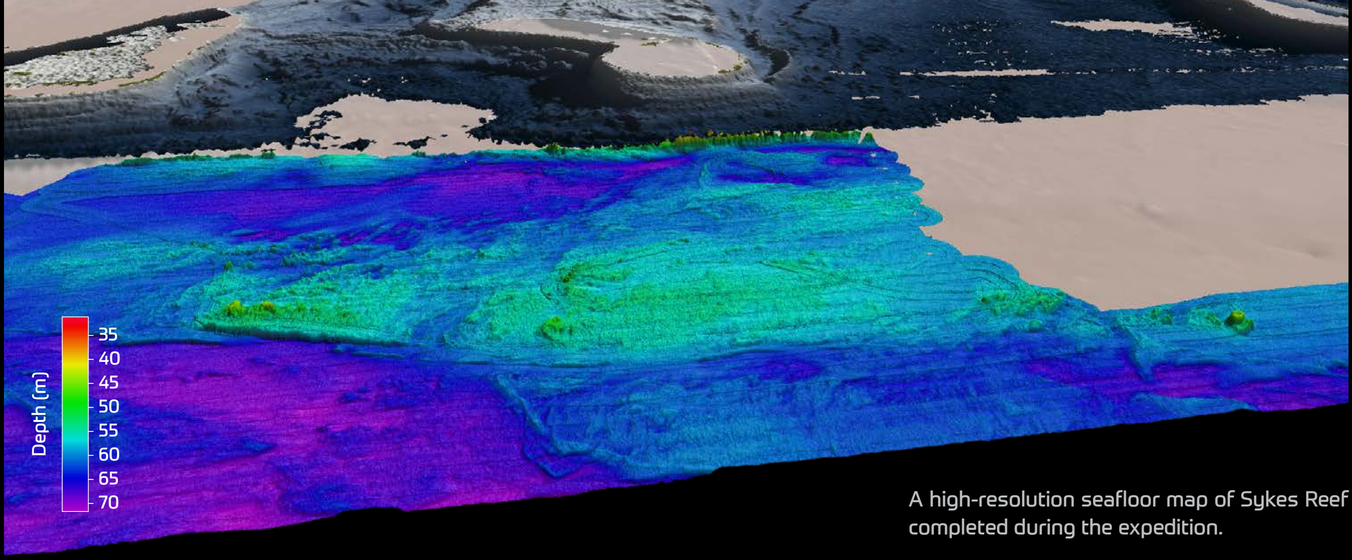


A high-resolution map of Capricorn Ridge showing drowned reef and contoured drift deposits.

CREATIVE TIES: ARTIST-AT-SEA

Three Australian artists sailed on R/V *Falkor*, incorporating the onboard science into their work. In January 2020, Angela Rossen used images of specimens collected to inspire her paintings and drawings—some of which she shared with school children throughout Western Australia. In November 2020, Indigenous contemporary artist Taloi Havini participated in a mapping voyage to find inspiration for an installation that will be featured in her first international solo exhibit at Ocean Space, Venice, Italy, in 2021. As 2020 came to a close, sculpture artist Jessica Leitmanis inspired the science team to develop a method for microplastics sampling on board after sharing her unique work with marine debris rope. The artist's pieces are now featured in SOI's online gallery and will be included in future exhibitions.

Angela Rossen



A high-resolution seafloor map of Sykes Reef completed during the expedition.

PINGING IN THE NEW YEAR

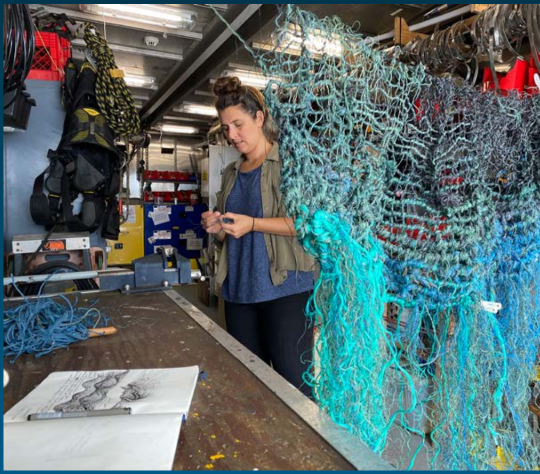
Led by Helen Bostock, University of Queensland, in collaboration with Derya Gurer, University of Queensland; Robin Beaman, James Cook University; Jody Webster and Maria Seton, University of Sydney; Kim Picard and Brendan Brooke, Geoscience Australia; Eric Woehler, Australasian Seabird Group; and Martin Russell, Coral Sea Marine Park

Australian scientists aboard R/V *Falkor* literally pinged in the new year, flying the first official flag of The Nippon Foundation-GEBCO Seabed 2030 Project and collecting the first seafloor mapping data of the United Nations Decade of Ocean Science for Sustainable Development. The team mapped almost 40,000 km^2 of seafloor in the Tasman and Coral Seas—providing new detail of Recorder, Fraser, and other unnamed seamounts. The maps created will aid in the management of the Coral Sea Marine Park and will be made publicly available through Seabed 2030 and the AusSeabed Marine Data Portal.

The science team aboard R/V *Falkor* holds the first official Seabed 2030 flag.

Taloi Havini

Jessica Leitmanis



WHAT'S NEXT Overcoming a Tumultuous Year

By Alan P. Leonardi, Robert D. Ballard, and Adam Soule

The past year has been difficult. Many friends and loved ones were lost during the coronavirus pandemic. All of us had to adjust, adapt, and learn new ways to live and work together while keeping healthy and safe in a virtual workspace. During this time, the NOAA Office of Ocean Exploration and Research, the Ocean Exploration Trust, and the Schmidt Ocean Institute continued their unique partnership to map, explore, and characterize the ocean while supporting goals of the blue economy. The partners advanced this mission by using virtual tools such as telepresence and new technologies to explore the deep ocean remotely, and most importantly, by drawing on the resilience and creativity of their people.

NOAA's Office of Ocean Exploration and Research suspended ship operations in 2020. Nevertheless, through external commercial agreements and federally funded opportunities with academic institutions, OER was still able to make progress toward achieving the goals of the new *National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone* (NOMEC, 2020). In a year of shutdowns due to personnel considerations, 2020 highlighted the true potential for uncrewed systems to explore the ocean. During OET's three-and-a-half month abbreviated expedition season along the west coast of the United States and Canada, for example, many of the people supplying science and outreach expertise, including dive leads, participated from shore. In addition, as part of its engagement mission, OER collaborated with OET and SOI on a new education website that includes oceanographic exploration content created by all three partners.

At the Ocean Exploration Cooperative Institute, based at the University of Rhode Island, new and exciting ocean exploration and mapping technologies continued to progress from early stage development to sea trials. These new technologies are helping to guide the final major ship upgrades to OET's E/V *Nautilus*, now in progress, to enable multiplatform missions to investigate the still largely unexplored US EEZ. New and emerging technologies will force-multiply and enhance exploration capabilities, informing new modes of operation among OER, its partners, and the broader oceanographic community. The OECI will begin testing these new concepts off the California coast in 2021 and then work them into OET expeditions in the central and western Pacific, as E/V *Nautilus* relocates to a base in Honolulu, Hawai'i, in the second half of 2021.

Looking ahead, OER's early season will begin with a technology demonstration on *Okeanos Explorer*. AUV *Orpheus* will be deployed to aid in the development of Terrain Relative Navigation for AUVs that can work at full ocean depths. OER also expects to fulfill commitments during the 2021 field season for mapping and exploration campaigns off the US East Coast as well as meet international objectives through expeditions that support the Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE) and Atlantic Ocean Research Alliance (AORA). This will begin with a transit by *Okeanos Explorer* along the New England Seamount Chain to the Corner Rise Seamounts for a high-seas expedition within the Sargasso Sea. Ship personnel, scientists, and researchers are also eagerly eyeing future exploratory work in 2022 with US and European partners along the Mid-Atlantic Ridge before *Okeanos Explorer* relocates to the Pacific Ocean.

A brittle star on a deep-sea octocoral found while ROV *SuBastian* dives on the South Diamond Islet/Tregrosse Reef in Coral Sea Marine Park off the east coast of Australia on the Queensland Plateau. *Image credit: Schmidt Ocean Institute*

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Shrimp and coral delight viewers during one of ROV *SuBastian*'s dives during an exploration of the Ribbon Reef Canyons, ~170 km northeast of Cairns, Australia. *Image credit: Schmidt Ocean Institute*

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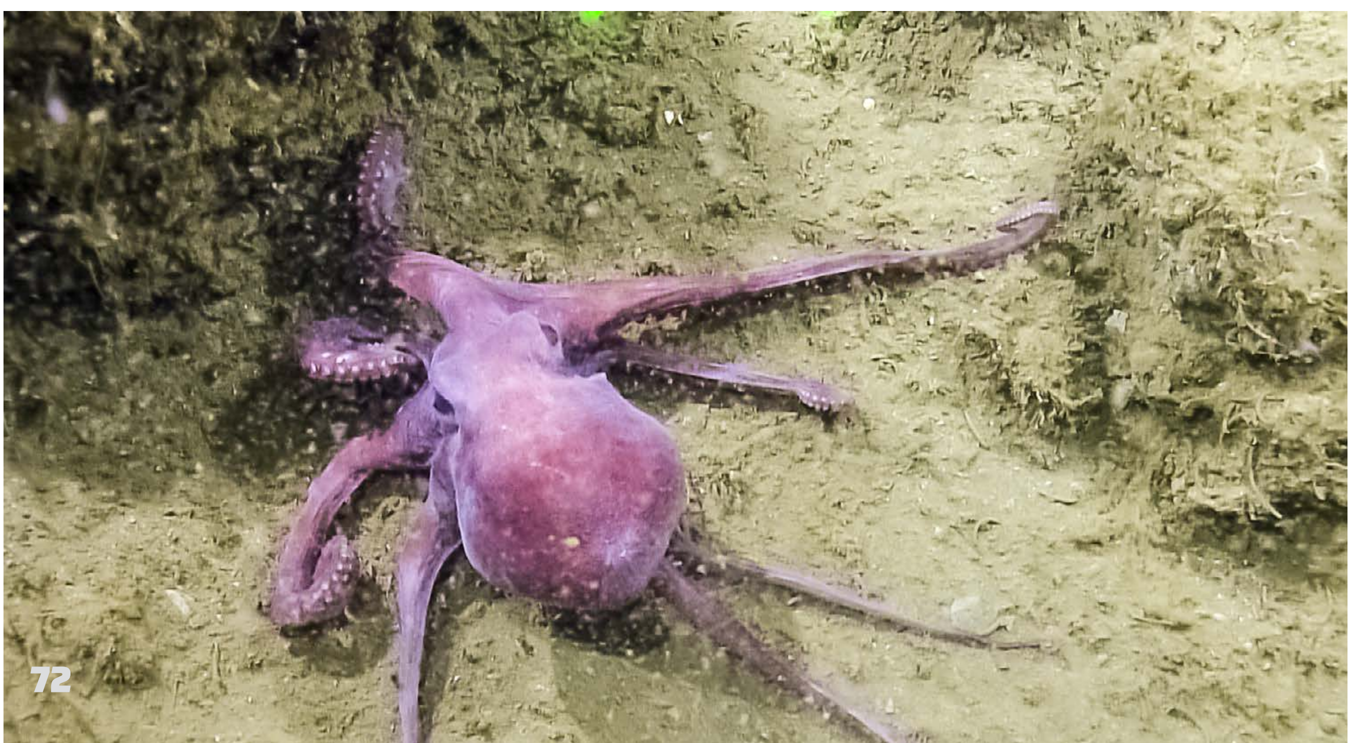
A deepwater octopus observed during explorations of the Olympic Coast National Marine Sanctuary (NA121). *Image credit: Ocean Exploration Trust/Nautilus Live*



Deepwater glass sponges (*Heterochone* sp.) and associated feather stars observed during explorations of the Olympic Coast National Marine Sanctuary (NA121). *Image credit: Ocean Exploration Trust/Nautilus Live*

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We must accept finite disappointment, but never lose infinite hope.

– Martin Luther King Jr.

As 2021 begins, the NOAA Office of Ocean Exploration and Research looks back at a year filled with devastating loss of life and the stark realities of systemic racism and political factionalization. In March 2020, OER met the emergence of the COVID-19 pandemic with postponement of *Okeanos Explorer* operations. Using remote work models, the program turned toward development of its universal exploration products and stepped up its virtual presence to connect more vigorously with the exploration community and educators. Using the strength of a skilled nationwide team, and strategic partnerships, OER's approach was to keep moving forward to advance the nation's ocean exploration program. We acknowledge the resilience and determination of the many individuals and partners who made this happen.

OER would like to acknowledge (acting) Chief of Operations Mashkoor Malik and Graphics Lead Matthew King for their expertise and creative contributions to this year's supplement and Michael Ford of NOAA Fisheries for his initiation of the Secrets of the Seas public program.

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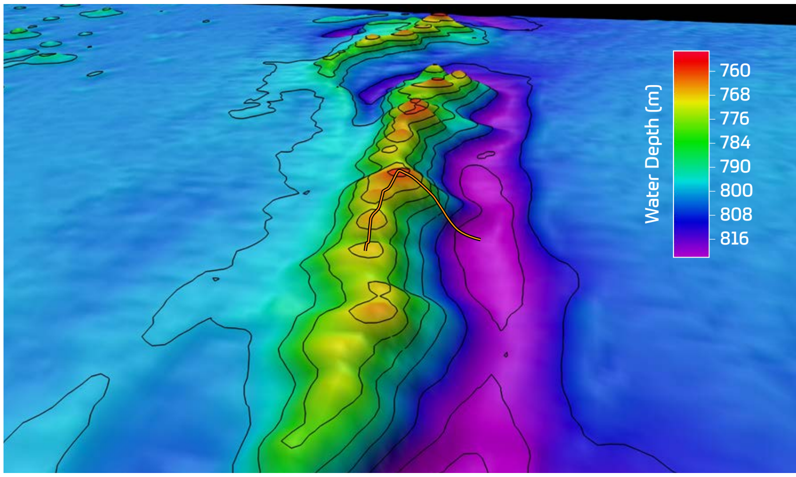
Deep waters off the southeastern United States remain poorly mapped and characterized. Seafloor maps made using data collected by *Okeanos Explorer* provide critical baseline information about this region. The orange line shows the track of ROV *Deep Discoverer* while exploring Blake Plateau. *Image credit: Southeastern US Deep-Sea Exploration expedition/NOAA OER.*



The impact of seeps on the ocean is an emerging area of research, in part driven by their newly quantified abundance in the ocean. In this image from Oregon's deep sea, a sea cucumber can be seen filter feeding in addition to sponges and corals that are making use of the hard rocks created by seepage. *Image credit: Dan Fornari, WHOI MISO Facility and OET Cruise NA095.*

ABOVE. Methane seeps are epicenters of biological activity and interactions at macroscopic and microbial scales, making them perfect places to seek biopharmaceutical or biotechnical compounds. This image, taken during the OER-supported Gradients of Blue Economic Seep Resources expedition, shows a mass of brittle stars on top of chemosynthetic clams abutting a methane hydrate site. *Image credit: Dan Fornari, WHOI MISO Facility and OET Cruise NA095.*

LEFT. This crinoid with a large number of arms was observed living on a coral stalk during the fourth dive of the 2019 Southeastern US Deep-Sea Exploration expedition off the coast of Florida in the Stetson-Miami Terrace Deepwater Coral Habitat of Particular Concern (HAPC). As part of the HAPC, the dive site was a priority for resource managers who were interested in learning more about deep-sea coral and sponge habitat in the area. *Image credit: NOAA OER*

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Acronyms

ADCP — Acoustic Doppler Current Profiler

ASPIRE — Atlantic Seafloor Partnership for Integrated Research and Exploration

ASV — Autonomous Surface Vessel

AUV — Autonomous Underwater Vehicle

CHNMS — Chumash Heritage National Marine Sanctuary

CINMS — Channel Islands National Marine Sanctuary

eDNA — Environmental DNA

EEZ — Exclusive Economic Zone

EPP — Educational Partnership Program

EV — Exploration Variable

E/V — Exploration Vessel

GFOE — Global Foundation for Ocean Exploration

ISC — Inner Space Center

LED — Light Emitting Diode

MBNMS — Monterey Bay National Marine Sanctuary

MISO — Multidisciplinary Instrumentation in Support of Oceanography

NHT — *Nereid Hybrid Tethered*

NCEI — NOAA National Centers for Environmental Information

NOAA — National Oceanic and Atmospheric Administration

NOMEC — National Ocean Mapping, Exploration, and Characterization

NUI — *Nereid Under Ice*

NSF — National Science Foundation

OCNMS — Olympic Coast National Marine Sanctuary

OECI — Ocean Exploration Cooperative Institute

OER — NOAA Office of Ocean Exploration and Research

OET — Ocean Exploration Trust

ONC — Ocean Networks Canada

ROV — Remotely Operated Vehicle

R/V — Research Vessel

SOI — Schmidt Ocean Institute

STEM — Science, Technology, Engineering, and Mathematics

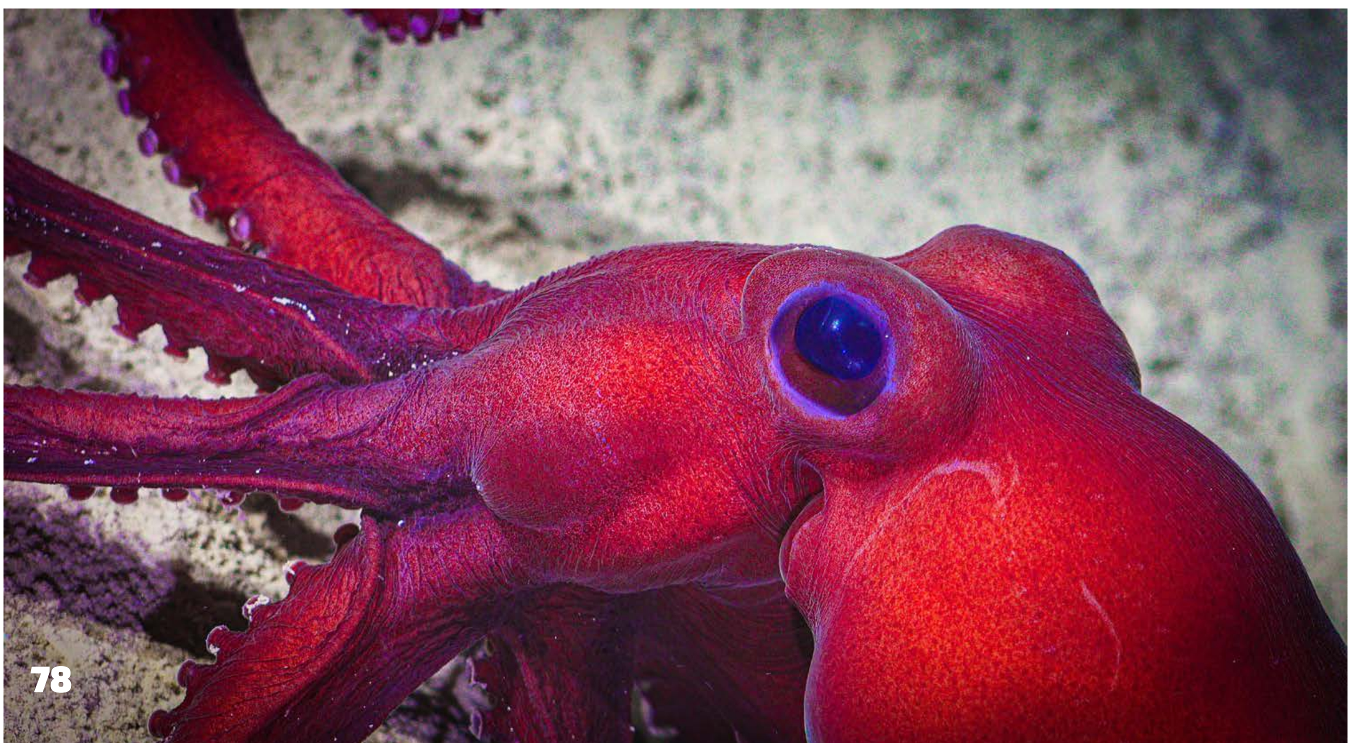
STEAM — Science, Technology, Engineering, Arts, and Mathematics

UNOLS — University-National Oceanographic Laboratory System

URI/GSO — University of Rhode Island's Graduate School of Oceanography

WHOI — Woods Hole Oceanographic Institution

This octopus (*Muusoctopus* sp.) was observed at nearly 1,200 m depth with ROV *SuBastian* while exploring the mid-section of a canyon that connects directly to the shallow waters of the Great Barrier Reef. *Image credit: Schmidt Ocean Institute*



ON THE BACK COVER. A tiny (~ 1 cm) *Hippocampus bargibanti*, also known as Bargibant's seahorse or the pygmy seahorse found at 114 m depth in Great Barrier Reef Marine Park by ROV *SuBastian*'s pilots. *Bargibanti* pygmy seahorses are extreme habitat specialists, spending their entire adult life on a single gorgonian coral. *Image credit: Schmidt Ocean Institute*

This amazing siphonophore was spotted during a livestream in Perth Canyon, Australia, at nearly 1,000 m depth. It is a colony of specialized individuals (zooids) that have different functions (e.g., capturing prey, movement). Despite different functions, all zooids in colonies are genetically identical. *Image credit: Schmidt Ocean Institute*

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