NAUTILUS LIVE
OCEAN EXPLORATION TRUST

THE OCEAN EXPLORATION TRUST
2023 FIELD SEASON

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CONTENTS

INTRODUCTION

Daniel Wagner and Allison Fundis

This annual report marks the fifteenth year anniversary of Ocean Exploration Trust's (OET) E/V *Nautilus* exploring poorly known parts of our global ocean in search of new discoveries. Since its first season in 2009, E/V *Nautilus* has conducted a total of 158 expeditions that explored our ocean throughout the Black Sea, Mediterranean, Atlantic, Caribbean, and Pacific for a total of 1,970 days at sea (~5.5 years). These scientific expeditions included a total of 1,017 successful ROV dives, as well as mapped over 1,053,000 km^2 of seafloor. The results of these exploratory expeditions have been summarized in over 300 peer-reviewed scientific publications covering a wide range of scientific disciplines, including marine geology, biology, archaeology, chemistry, technology development, and the social sciences.

Throughout its 15-year history, E/V *Nautilus* has been not only a platform for ocean exploration and discovery, but also an inclusive workspace that has provided pathways for more people, especially those early in their careers, to experience and enter ocean exploration professions. It has also catalyzed numerous technological innovations, multi-disciplinary collaborations, and inspired millions through OET's extensive outreach initiatives. The 2023 field season was no exception, with E/V *Nautilus* undertaking 12 multi-disciplinary expeditions that explored some of the most remote and poorly surveyed areas in the Pacific, all of which included numerous activities to share expedition stories with diverse audiences across the globe.

As in previous years, E/V *Nautilus* began its 2023 operations with a shakedown expedition to complete a series of engineering tests in preparation for the field season, and then conducted expeditions focused on mapping and remotely operated vehicle operations in the Hawaiian Islands, the US Pacific Remote Islands, and British Columbia. Three of these expeditions included the deployment of vehicles from partners of the NOAA Ocean Exploration Cooperative Institute, a consortium of oceanographic institutions that brings together the expertise and capabilities of the University of Rhode Island, University of New Hampshire, Woods Hole Oceanographic Institution, University of Southern Mississippi, and OET to advance the core priorities of NOAA Ocean Exploration. These technology demonstration expeditions showcased the value of combining complementary ocean exploration technologies, in addition to inter-institutional collaborations, to accelerate the pace by which we can effectively explore our ocean. In addition to work aboard E/V *Nautilus*, the 2023 field season also included one entirely shore-based mission to explore the complex underwater cave system at Wakulla Springs, work that was conducted in collaboration with Stone Aerospace, Karst Underwater Research, and OET.

Stories and discoveries from OET expeditions were shared with diverse audiences via various avenues, collectively reaching millions around the world. Across the 2023 field season, expedition teams hosted 710 live interactions from the broadcast studio onboard E/V *Nautilus*, welcomed aboard 80 students and educators, grew its social media presence, developed dozens of new education resources, and worked to promote our work via 3,845 media stories, including several that had a press reach in the billions.

The accomplishments of the 2023 field season were only possible thanks to the many partners that contributed to this work, including both ship-based and shore-based partners that are detailed throughout this report. In 2023, OET continued to build on its long-standing collaborations with NOAA Ocean Exploration, NOAA Ocean Exploration Cooperative Institute, Office of Naval Research, Ocean Networks Canada, National Geographic Society, National Marine Sanctuary Foundation, Museum of Comparative Zoology, Marine Geological Samples Laboratory, as well initiated new partnerships with the Defense POW/MIA Accounting Agency, Bureau of Ocean Energy Management, Ocean Census, STEMSEAS Program, Ocean Census, Palau International Coral Reef Center, and others. These partnerships focused not only on gaining new information about our largely unexplored ocean, but also on how to meaningfully share this knowledge with a wide array of stakeholders, particularly those from geographies where OET operates. In particular, we continued our ongoing collaboration with partners in Hawaiʻi—including staff of the Papahānamokuākea Marine National Monument and the Hawaiian Cultural Working Group facilitated by the Office of Hawaiian Affairs—to ensure our expeditions to places that hold cultural significance to Native Hawaiians were planned and implemented in a way that incorporated Hawaiian worldview, participation, and input.

TECHNOLOGY

Samantha Wishnak, Josh Chernov, Derek Sowers, Matt Koskela, Megan Cook, Allison Fundis, and Daniel Wagner

E/V *NAUTILUS*

The Exploration Vessel (E/V) *Nautilus* is an efficient 68-meter ship, with berthing for 17 permanent crew members in addition to up to 35 berths for rotating members of the *Nautilus* Corps of Exploration. The ship is equipped with remotely operated vehicles (ROVs), acoustic mapping systems, and various other state-of-the-art technologies. E/V *Nautilus* has a data lab for processing digital data, as well as a wet lab for processing physical samples. As part of the Ocean Exploration Trust's effort to share expeditions with the broader scientific community and the public, 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.

GENERAL

BUILT: 1967, Rostock, Germany

LENGTH: 68.23 meters (224 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 standard, 12 knots maximum

FUEL CAPACITY: 330 cubic meters

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

SHIP SERVICE GENERATORS: Two 585 kilovolt-ampere generators, one 350 kilovolt-ampere generator

PORTABLE VAN SPACE: Four 6.1-meter (20-foot) vans

COMPLEMENT: 17 crew, 35 science and operations

FLAG: Saint Vincent and the Grenadines

ADDITIONAL EQUIPMENT:

- Dynacon 369i ROV winch with 7,000 meters (23,000 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
- Hawbolt painter boom with winch, 1.5 metric tons safe working load with 7-meter reach off starboard side
- Two airtuggers, safe working load 900 pounds each
- A-frame, 8 tons safe working load
- Two rescue boats, crane and davit, 0.9 metric tons safe working load

TELEPRESENCE TECHNOLOGY

VSAT: 2.4-meter stabilized Sea Tel 9711 uplink antenna capable of C- and Ku-band operation of up to 20 megabits per second (C-band circular or linear)

REAL-TIME VIDEO STREAMING: Six Haivison Makito X encoders streaming live video via satellite to the Inner Space Center at the University of Rhode Island

CAMERAS: 24 high-definition cameras: aft port, amid and starboard (pan/zoom/tilt), 180° wide aft, transom, bow, control room (8), 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 Wi-Fi
- 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: Eight workstations for seafloor mapping and other data processing, including work space for science managers, data loggers, navigators, educators, data engineers, satellite engineers, and video engineer

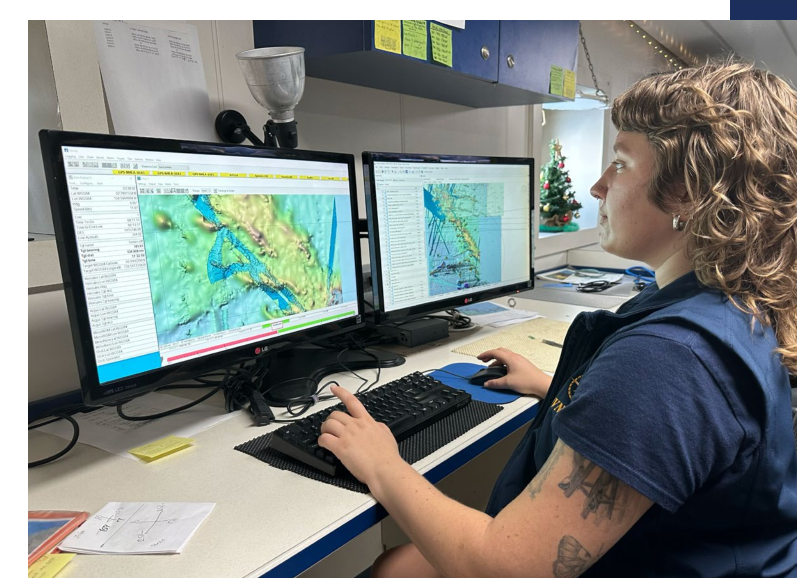
RACK ROOM

AREA: 17.3 square meters (185 square feet)

DATA STORAGE: 50 terabyte onboard storage for non-video data, 150 terabyte disk storage for video data

EMERGENCY COMMUNICATIONS: Iridium phone, KVH phone

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

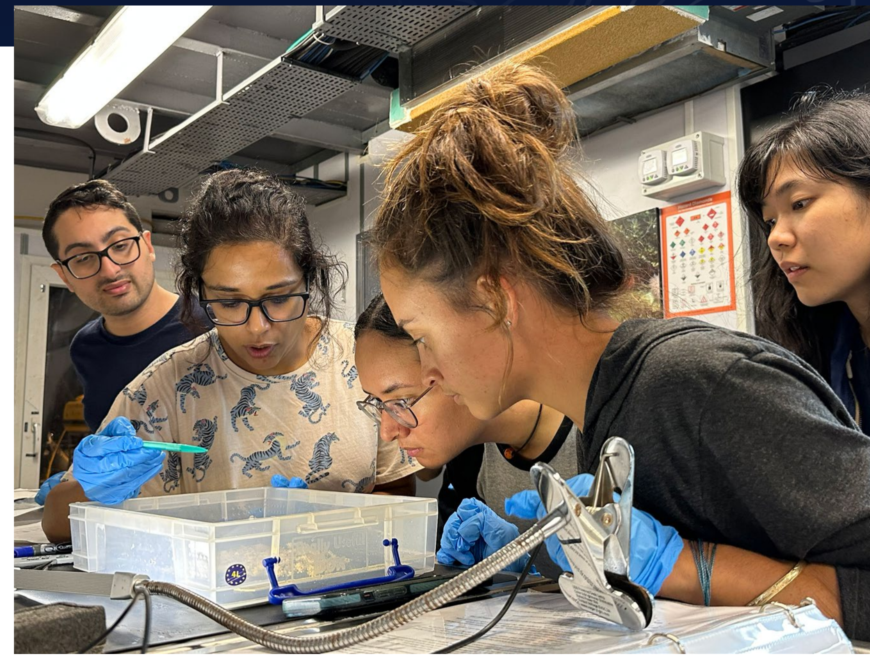


PRODUCTION STUDIO

AREA: 12 square meters (130 square feet)

CAMERA: 4k Panasonic BGH1 studio camera, Sony A1 camera kit for topside video with live broadcast capacity via Teradek 500

PRODUCTION: 10-input video production switcher for live-produced interactions, full production editing workstation with ship-to-shore transmit capacity for remote production needs



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:

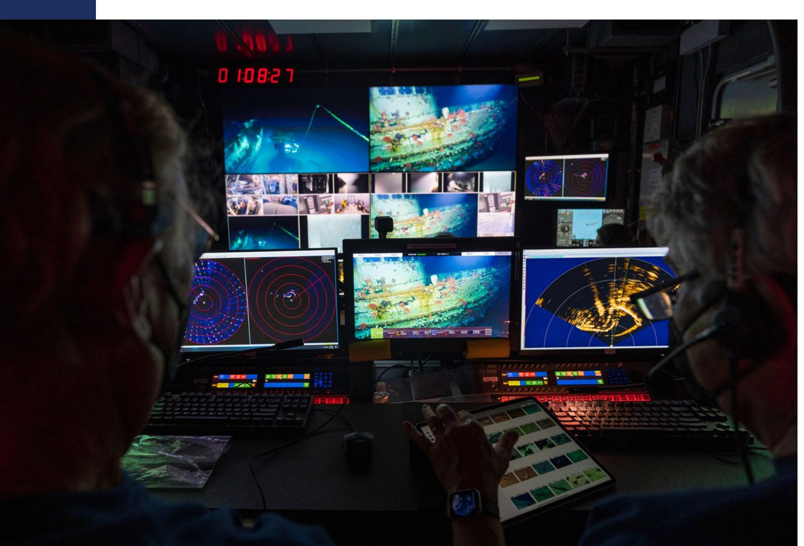
- Panasonic MDF-C8V1 ULT –80°C/–86°C scientific freezer, 0.085 cubic meters (3 cubic feet)
- Two science refrigerators, approximately 0.57 cubic meters (20 cubic feet) each
- Science freezer, –20°C, 0.14 cubic meters (5 cubic feet)

HAZMAT:

- Fume hood
- Two HAZMAT lockers for chemical and waste storage

MICROSCOPE: Zeiss Primo Star Binocular Microscope, 4x, 10x, 40x, 100x

ROCK SAW: MK Diamond Products MK-101-24 Tile Saw



ROV HANGAR

AREA: 24 square meters (258.3 square feet)

POWER: 110/60 hertz and 220/50 hertz available

PERSONAL PROTECTIVE EQUIPMENT: Hard hats, personal flotation devices, 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: 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 workstations, typical configuration for ROV operations includes workstations for ROV pilot, co-pilot, navigator, video engineer, data logger, educator, and 2-4 for scientists

VIDEO RECORDING AND STORAGE: Two Cinedeck ZX85 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 multibeam echosounder composed of two long transducer arrays mounted in a T-shape on the hull of E/V *Nautilus*. The EM 302 can map the seafloor at ship speeds up to 12 knots.

FREQUENCY: 30 kilohertz

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

PULSE FORMS: CW and FM chirp

ANGULAR RESOLUTION: 1° × 1°

APPROXIMATE SWATH WIDTH: 1–5 times water depth, up to 8 kilometers (5 miles)

SOUNDINGS PER SWATH: Up to 423 in single swath mode, 864 in dual swath mode

APPROXIMATE GRID RESOLUTION: 1%–5% water depth (e.g., 10–50 meters [33–164 feet] at 1,000 meters [3,281 feet] depth)

KNUDSEN 3260 SUB-BOTTOM PROFILER

The Knudsen 3260 is a sub-bottom echosounder mounted inside the hull of E/V *Nautilus*. It operates at low frequencies so that emitted sound can penetrate layers of sediment to about 80 meters below the seabed surface.

OPERATING FREQUENCY: Dual frequency, 3.5 and 15 kilohertz

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

RANGE: 50 meters to full ocean depth

KONGSBERG SIMRAD EC150-3C TRANSDUCER

The Kongsberg Simrad EC150-3C is a hull-mounted transducer on E/V *Nautilus* that combines an acoustic Doppler current profiler (ADCP) and an EK80 split-beam fisheries sonar into one instrument. The ADCP measures the speed and direction of currents underneath the ship, whereas the split-beam echosounder maps features found within the water column.

FREQUENCY: 150 kilohertz (130-170 kilohertz range)

MAX DEPTH RANGE: About 130 meters (426 feet)

BEAMWIDTH: 3° at 150 kilohertz

PULSE FORMS: CW or FM

ADCP NUMBER OF BEAMS: 4

ADCP DEPTH BIN CELL SIZE: customizable between 2-16 meters (6.5-52.5 feet)

ULTRA-SHORT BASELINE NAVIGATION SYSTEM

The ultra-short baseline (USBL) navigation system helps track the position of the ROVs in the water. The system consists of a hull-mounted transceiver on E/V *Nautilus*. Each ROV is outfitted with a transponder beacon to allow acoustic signals between the ship and each vehicle to determine their positions.

SYSTEM: Sonardyne Ranger 2 with Lodestar GyroUSBL transceiver deployed from the moonpool for USBL tracking

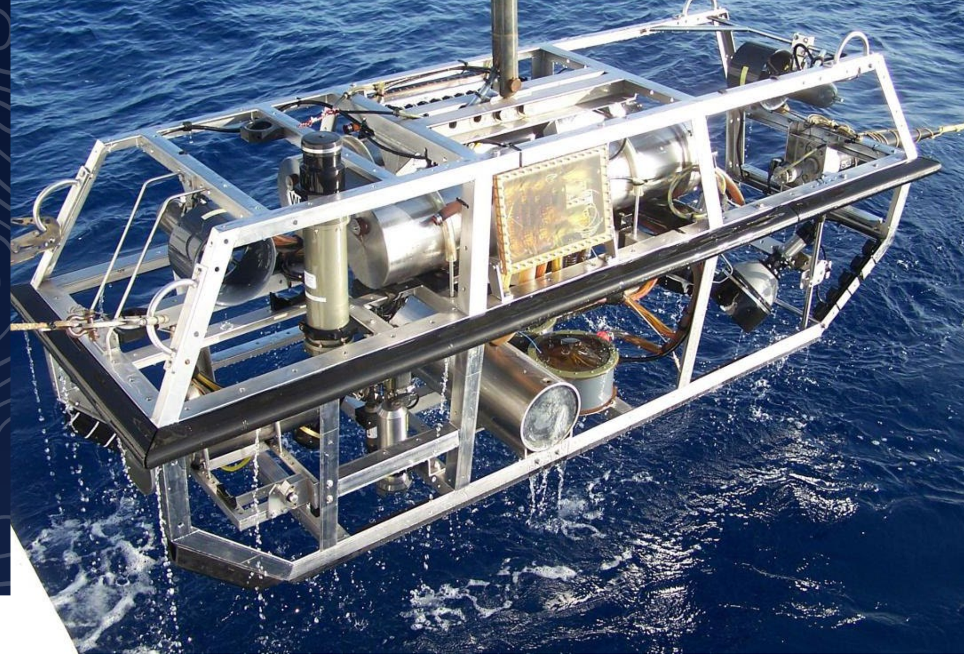
RANGE: Up to 7,000 meters (22,966 feet)

POSITIONING ACCURACY: 0.5% of slant range

OPERATIONAL COVERAGE: ±90°

OPERATING FREQUENCY: 19–34 kilohertz

TARGETS TRACKED: *Hercules* or *Little Hercules*, *Atalanta* or *Argus*, and two additional transponders are available. More vehicles can be tracked with the addition of compatible Sonardyne transponders



REMOTELY OPERATED VEHICLE (TOWSLED) *ARGUS*

ROV *Argus* is a deep-tow system capable of diving to 6,000 meters. *Argus* is mainly used in tandem with ROV *Hercules* or *Little 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 deep-water survey missions.

GENERAL

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

CABLE: 7,000 meters (23,000 feet) of 1.73 centimeter (0.681 inch) diameter electro-optic Rochester cable, 3x #11 conductors, 4x 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 per minute (98 feet per minute)

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: Sonardyne Ranger 2

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

PRESSURE SENSOR: Paroscientific Digiquartz 8CB series

ALTIMETER: Benthos PSA-916

FORWARD-LOOKING SONAR: Mesotech 1071, 300 kilohertz, 0.5–100 meter (1.6–328.1 feet) range typical

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

SCIENTIFIC INSTRUMENT SUPPORT

POWER: 110 volt 60 hertz AC, 24 VDC and 12 VDC power options

DIGITAL DATA CHANNELS: Ethernet

REMOTELY OPERATED VEHICLE *HERCULES*

ROV *Hercules* works in tandem with towsled *Argus* or *Atalanta* to explore 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. High-resolution mapping tools can also be mounted on the ROV upon request. *Hercules* can carry up to 113 kilogram (250 pounds) of samples or tools between the seafloor and the surface.

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 per second (1.5 knots) forward, 0.25 meters per second (0.5 knots) lateral, 0.5 meters per second (1 knot) vertical (on site, within tether range)

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

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

MAXIMUM SAMPLING TRANSIT SPEED: 0.25 meters per second (0.5 knots) on flat seafloor, <0.13 meters/second (<0.25 knots) over complex 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 per minute (98.4 feet per minute), 15 meters per minute (49.2 feet per minute), or 20–22 meters per minute (65.6–7.2 feet per minute) average

PROPULSION

- Six hydraulic thrusters powered by 15 kilowatt (20 horsepower), 207 bar (3,000 pounds power square inch) hydraulic system
- Fore/Aft & Vertical – Four 27.94 centimeter (11 inch) ducted thrusters, each providing 900 newton (200 pounds of force) thrust
- Lateral – Two 22.86 centimeter (9 inch) ducted thrusters, each providing 450 newton (100 pounds of force) thrust

VEHICLE SENSORS & NAVIGATION

SYSTEM: NavEst integrated navigation system solution

HEADING AND ATTITUDE

- Primary Heading – IXSEA Octans III 7600 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 kilohertz, 0.7–90 meter range (2.3–295.3 feet)

FORWARD-LOOKING SONARS

Kongsberg Mesotech 1071 scanning sonar, tunable from 400–1,000 kilohertz; range to 200 meter (656 feet) at 450 kilohertz; range resolution up to 3.75 millimeter (0.15 inch)

TriTech Super SeaKing V7 scanning sonar, 325 or 675 kilohertz; range 0.4–300 meters (1.3–984 feet); range resolution 0.015 meter (0.05 feet)

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-meter rated, Zeus Plus with 10× zoom lens, Ikegami HDL-45A with zoom/pan/tilt/extend, 1080i SMPTE 292M output format
- Insite Pacific, 6,000-meter 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: Fifteen DeepSea Power & Light SeaLite Sphere LED lights, 6,000 lumens, mounting configurable

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

STILLS IMAGING CAMERA: One low-light sensitive 24 megapixel 6k cinematic camera with a 16-35 millimeter lens controlled via ethernet. Fixed mounted.

MANIPULATORS & SAMPLING

MANIPULATORS

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

SUCTION SYSTEMS

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

SAMPLING TOOLS: Mission configurable:

- Up to five 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 × 33 × 25 centimeters (17.7 × 13 × 9.8 inches)
- Forward sample tray (outboard): 68 × 35 × 30 centimeters (26.8 × 13.8 × 11.8 inches)
- Starboard sample drawer: 65 × 50 × 30 centimeters (25.5 × 19.7 × 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 volt, 60 hertz AC
- 24 VDC
- 12 VDC

DIGITAL DATA CHANNELS

- RS-232: 115 kilobaud
- RS-485/422: 2.5 megabaud
- Ethernet: 10/100/1,000 megabits per second links available
- TTL: one TTL link

HYDRAULIC: Proportional and solenoid hydraulic functions

- 1,150 pounds per square inch at 5 gallons per minute
- 1,850 pounds per square inch at 5 gallons per minute
- 3,000 pounds per square inch at 5 gallons per minute (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
- Norbit wideband multibeam sonar - forward or downward facing
- 18 megapixel Ethernet connected digital still camera
- Low-light camera
- Modular soft grippers

REMOTELY OPERATED VEHICLE (TOWSLED) *ATALANTA*

Atalanta is a smaller version of *Argus* and 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 deep-water survey missions.

GENERAL

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

SIZE: 2.16 meters long × 1.0 meters wide × 1.2 meters tall (7 feet long × 3.28 feet wide × 3.94 feet tall)

WEIGHT: 1,000 kilograms (2,200 pounds) in air, 771 kilograms (1,700 pounds) in water

MAXIMUM TRANSIT SPEED: 2 knots

ASCENT/DESCENT RATE: 20–30 meters per minute (65–98 feet per minute)

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 500 kilohertz altimeter

FORWARD-LOOKING SONAR: Mesotech 1071, 300 kilohertz, 0.5–100 meter range

SCIENTIFIC INSTRUMENT SUPPORT

POWER: 110 volt 60 hertz AC, 24 VDC and 12 VDC power options

DIGITAL DATA CHANNELS: Ethernet, RS-232

REMOTELY OPERATED VEHICLE *LITTLE HERCULES*

ROV *Little Hercules* is a smaller sister to *Hercules* with 6,000-meter capability, 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.

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 (4.59 feet long × 3.28 feet wide × 3.93 feet tall)

WEIGHT: 400 kilograms (900 pounds) in air; 45.36 kilograms (100 pounds) payload

MAXIMUM TRANSIT SPEED: 2 knots

ASCENT/DESCENT RATE: 20–30 meters per minute, (65–98 feet per 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: Six 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 500 kilohertz altimeter

FORWARD-LOOKING SONAR: Kongsberg Mesotech 1071 scanning sonar, 675 kilohertz, 1–200 meter (3–656 feet) range typical

SCIENTIFIC INSTRUMENT SUPPORT

POWER: 110 volt 60 hertz AC, 24 VDC and 12 VDC power options

DIGITAL DATA CHANNELS

- RS-232 serial
- Ethernet: 10/100/1,000 megabits per second 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.

2023 TECHNOLOGY COLLABORATIONS

UNIVERSITY OF NEW HAMPSHIRE:
USV *DriX* and Universal Docking System

WOODS HOLE OCEANOGRAPHIC INSTITUTION:
AUV *Mesobot*

UNIVERSITY OF HAWAI'I:
Hadal Water Column Profiler

OREGON STATE UNIVERSITY:
Sexton still camera (on ROV)

OCEAN EXPLORATION TRUST:
Widefield Camera Array (on ROV)

UNIVERSITY OF RHODE ISLAND:
Deep Autonomous Profiler, Norbit wideband multibeam sonar (on ROV)

SETI INSTITUTE & IMPOSSIBLE SENSING:
Laser Divebot spectrometer (on ROV)

2023 REMOTELY OPERATED VEHICLE OPERATIONS OVERVIEW

Josh Chernov, Jonathan Zand, Trevor Shepherd, Robert Waters, Dan Cormany, Reuben Mills, and Keegan Holme

The 2023 field season included a series of upgrades to OET's remotely operated vehicles (ROVs) to continue maintaining its core functions and enhance its exploration capabilities. Throughout the season, the team worked hard to not only overhaul the design of ROV *Hercules*, but also integrate new tools to broaden its scientific applications. These efforts resulted in the successful completion of 85 ROV dives throughout the 2023 field season, during which the ROVs spent a total of 1,080 hours (45 days) exploring deep-sea environments throughout the Pacific.

ROV *HERCULES* FRAME AND FOAM UPGRADE

ROV *Hercules* was initially commissioned in 2003 for the primary purpose of studying ancient shipwrecks. Since then, ROV *Hercules* has undergone several modifications to enhance its overall capabilities, as well as adapt it to the study of other scientific disciplines, including geology, biology, and chemistry. Despite peripheral modifications over the past two decades, the core structure and operating system of ROV *Hercules* remained unchanged until recently.

A significant milestone in its evolution occurred during the off-season maintenance period from November 2022 to April 2023. During this timeframe, ROV *Hercules* underwent a major design overhaul, marked by the complete replacement of its aluminum frame and foam pack (Figure 1). The overarching project challenge involved preserving the integrity of the core operating components, while introducing a new frame and buoyancy module. This transformation aimed to enhance the strength of the frame and uphold the existing payload capacity, with only a modest increase in its weight. Remarkably, this ambitious redesign was successfully completed within a compressed window of only 5.5 months.

Facing time constraints, the core ROV team, consisting of Josh Chernov, Jonathan Zand, Trevor Shepherd, Robert Waters, and Dan Cormany (Figure 2), augmented their capabilities by enlisting design and drawing services from Durrance Design Group, represented by Reuben Mills and Keegan Holme. This collaborative effort brought together the collective expertise of both teams to embark on the comprehensive redesign of the entire ROV support structure. A key challenge of this endeavor was the introduction of a novel frame design concept that had to be strategically tailored to meet the specific design constraints of the vehicle.

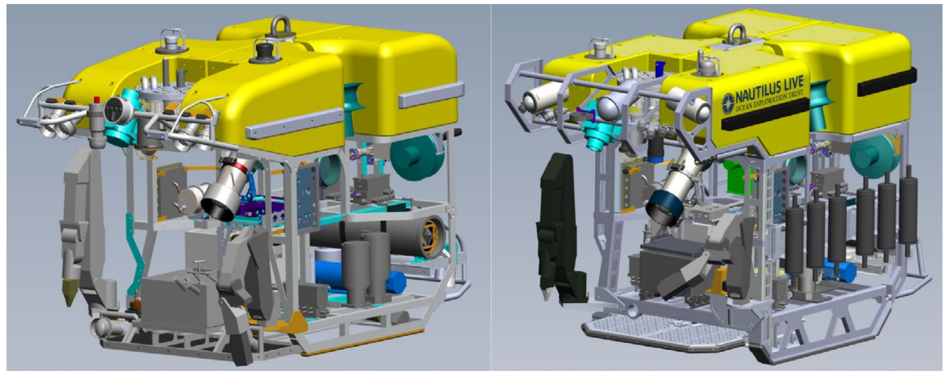


Figure 1. The original design of ROV *Hercules* in 2003 (left) and its current design after the 2023 refit (right).

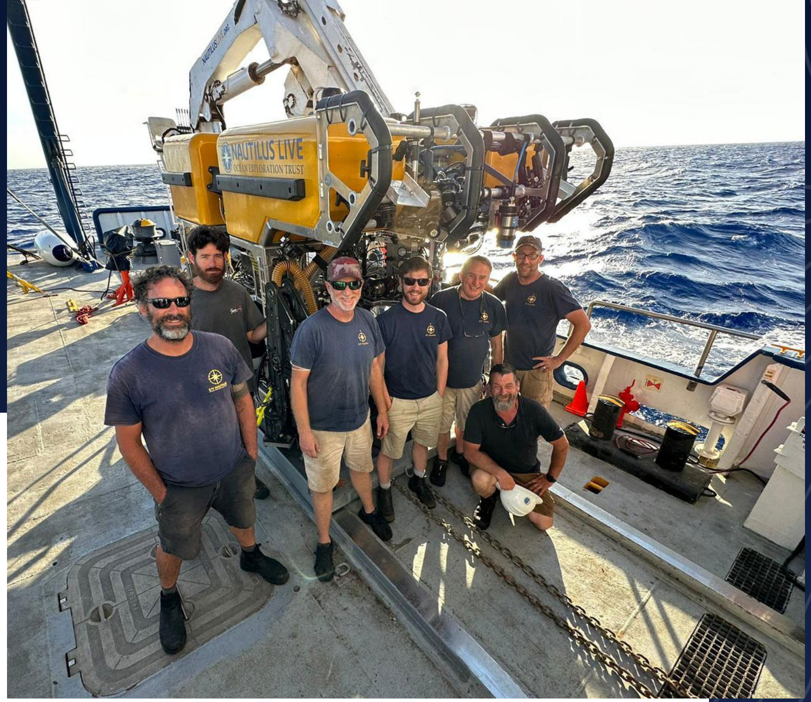


Figure 2. ROV *Hercules* and the operations team prior to its initial deployment after the successful refit of the vehicle.

During the period when the ROV redesign was completed, E/V *Nautilus* was docked at the University of Hawai'i Marine Center in Honolulu. The significance of the facilities and the dedicated personnel at the marine center cannot be overstated, as these were critical to the success of this project. The OET team benefited immensely from having a workspace adjacent to a fully equipped machine shop, which provided an excellent working environment, access to local tools and expertise. Additionally, the OET team sought the expertise of master machinist and ROV pilot and technician Dani Hinshaw. His skills and innovative ideas proved invaluable in addressing the challenges encountered throughout the project.

2023 ROV OPERATIONS

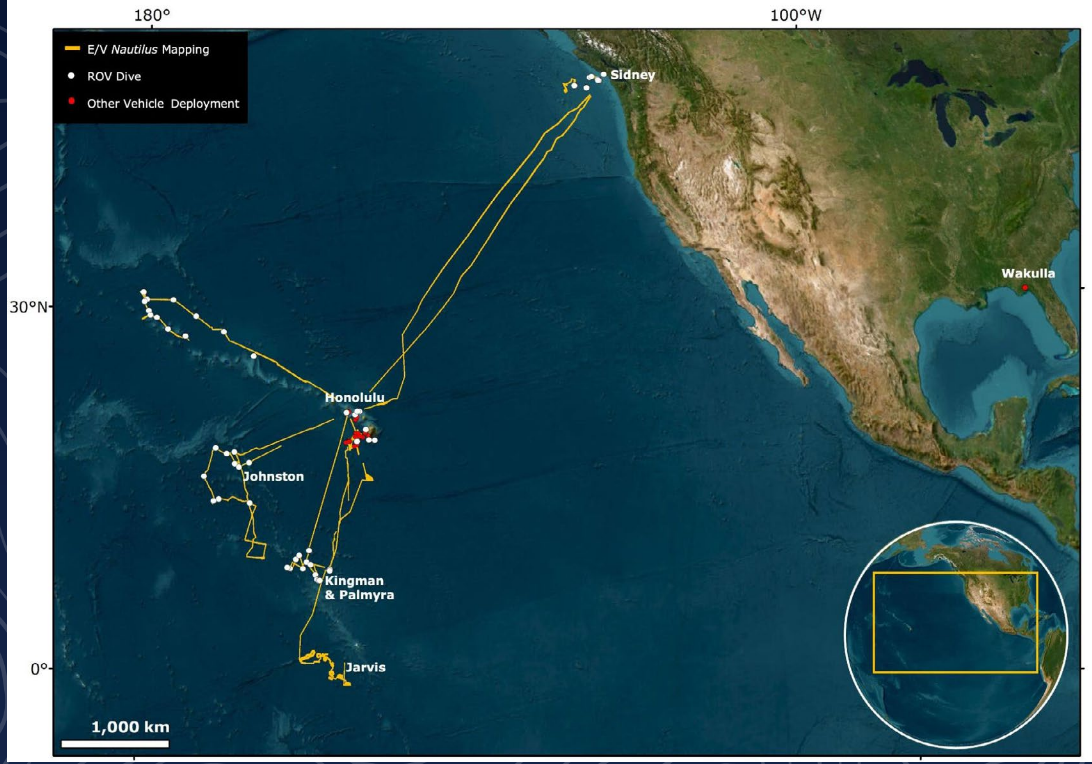
Once the frame of ROV *Hercules* was successfully rebuilt, the team was ready to embark on another exciting field season, which included ROV dives to explore Central Pacific seamounts, hydrothermal vents off British Columbia and Hawai'i, World War II wrecks associated with the Battle of Midway and the Pearl Harbor Attack, among many others.

The scientific accomplishments of these dives are summarized in detail throughout this report, but it also included numerous ROV engineering feats that made all this work possible. In particular, the 2023 field season included:

1. The first time ROV integration of the Laser Divebot Raman Spectrometer to collect data on the chemical composition of objects on the seafloor,
2. The development and first time ROV integration of a new Widefield Camera Array system to collect ultra-high-resolution imagery and immersive footage,
3. The deepest dives in the 15 year history of OET, which brought ROV *Atalanta* to depths exceeding 5,400 meters to survey three historically-significant aircraft carriers lost during the Battle of Midway, and
4. Assisting Ocean Networks Canada in the annual maintenance of their cabled observatory, work that relied on 20 ROV dives.

The accomplishments of the 2023 season were made possible thanks to the hard work and collective team effort involving OET and its extensive network of partners. Looking ahead, the ROV team eagerly anticipates the challenges of 2024 and beyond, building on the successes of past years.

Figure 3. Work spaces at the University of Hawai'i Marine Center (left). ROV team working on the vehicle refit (right).



2023 FIELD SEASON OVERVIEW

Daniel Wagner

In 2023, the Ocean Exploration Trust (OET) completed 13 multi-disciplinary expeditions that explored poorly known underwater environments over the course of 229 days, including one shore-based mission at Wakulla Springs and 12 expeditions aboard E/V *Nautilus* in the Pacific (above). The E/V *Nautilus* began its season with a shakedown expedition in the Main Hawaiian Islands, and then conducted a series of expeditions focused on seafloor mapping, ROV explorations, and integrating emerging exploration technologies. Collectively, 2023 expeditions mapped over 183,000 square kilometers of seafloor, and completed 85 successful ROV dives and 68 other vehicle deployments that surveyed a wide diversity of habitats and geological features, including seamounts, ridges, hydrothermal vents, caves, and World War II wrecks, among others.

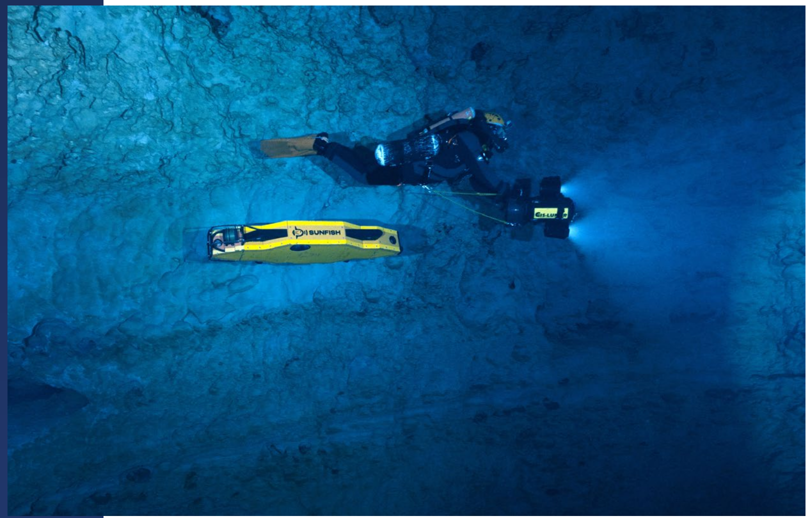


Figure 1. The shore-based Wakulla Springs expedition used a new cinema-grade camera, AUVs and technical SCUBA divers to image the complex underwater cave system at the Edward Ball Wakulla Springs State Park (photo credit: Michael Barnette).

WAKULLA SPRINGS

Between February 1–15, OET in collaboration with Stone Aerospace and Karst Underwater Research conducted a shore-based expedition to explore the complex underwater cave system at the Edward Ball Wakulla Springs State Park located south of Tallahassee, Florida (Figure 1). Funded by the Office of Naval Research, the mission used a new cinema-grade camera integrated onto autonomous underwater vehicle (AUV) *SUNFISH* and technical SCUBA divers to explore the cave system. The expedition completed 14 AUV dives and 28 technical SCUBA dives, during which ultra high-resolution imagery was collected and then used to generate detailed three-dimensional models of the caves.

2023 E/V *NAUTILUS* SHAKEDOWN (NA147–148)

Between April 24–May 13, E/V *Nautilus* conducted two back-to-back expeditions to complete routine shakedown operations in preparation for the 2023 field season (Figure 2). Over the course of 14 days at sea around the Main Hawaiian Islands, these two expeditions focused on shakedown operations of the ship's mapping, ROV and telepresence systems, as well as continued the integration of University of New Hampshire's uncrewed surface vehicle *DriX* into E/V *Nautilus* operations. Additionally, these expeditions included the first-time integration of the University of Hawaii's Hadal Water Column Profiler onto E/V *Nautilus*, as well as surveys of a 1941 plane wreck for the Defense POW/MIA Accounting Agency.

Figure 2. E/V *Nautilus* began the 2023 season with two back-to-back shakedown expeditions to test its systems.

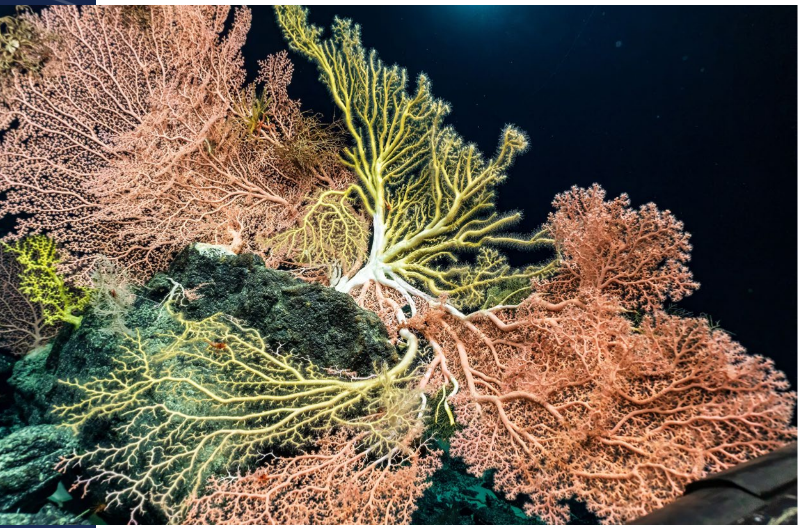


Figure 3. The E/V *Nautilus* expedition to Kingman Reef and Palmyra Atoll recorded high-density coral gardens at three locations in an area that has been identified for the designation of a new National Marine Sanctuary.

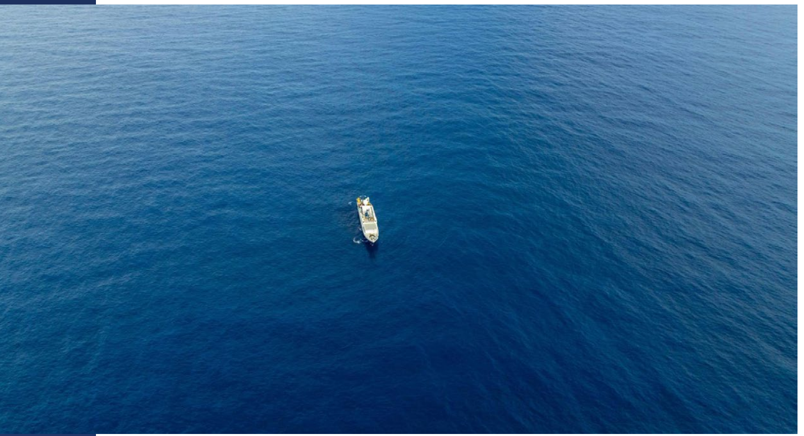


Figure 4. In June and July, the E/V *Nautilus* conducted two transit mapping expeditions that mapped previously unmapped seafloor between Hawaiʻi and British Columbia.

KINGMAN & PALMYRA (NA149)

Between May 16–June 14, E/V *Nautilus* explored the deep-sea biology and geology in US waters north of Kingman Reef and Palmyra Atoll. Funded by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, the expedition mapped over 24,095 square kilometers of seafloor and completed 16 ROV dives that explored ten different seamounts at depths between 1,100–3,100 meters. Noteworthy ROV observations included recording two new species of jellyfish, high-density coral gardens (Figure 3), a significant range expansion of bone-eating worms, as well as the collection of 192 samples to support ongoing studies on the biodiversity, geological age, and volcanic history of the region. In addition to exploring previously unsurveyed areas, the expedition included the first-time ROV integration of a Raman spectrometer. The spectrometer was used to collect *in situ* data on the chemical composition of the seafloor, which will be compared to lab-based analyses of collected samples to develop new tools for ocean exploration.

HAWAIʻI-BRITISH COLUMBIA TRANSIT MAPPING (NA150 & NA152)

From June 16–25 and July 19–31, E/V *Nautilus* conducted two transit mapping expeditions in the Northeast Pacific (Figure 4). Funded by Ocean Networks Canada with additional support from NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, these expeditions mapped seafloor during transits between British Columbia and Hawaiʻi, focusing on areas that had not previously been mapped. During a combined 21 days at sea, these expeditions mapped over 47,472 square kilometers of seafloor, which mostly consisted of abyssal plains, but also included passage over unmapped portions of the Mendocino, Pioneer, and Murray fracture zones, as well as several unnamed seamounts. In addition to transit mapping, one of the expeditions (NA152) included a backscatter calibration exercise of E/V *Nautilus*' multibeam sonar, which was closely coordinated with NOAA to develop standardized methodologies between different programs.

OCEAN NETWORKS CANADA NEPTUNE OBSERVATORY (NA151)

Between June 25–July 18, E/V *Nautilus* conducted a 21-day expedition to provide maintenance support to Ocean Networks Canada's cabled NEPTUNE observatory. Located off the coast of British Columbia, the observatory consists of an 800-kilometer loop of fiber optic cable that connects numerous instruments across five sites, thereby providing high-resolution temporal observations not afforded by traditional ship-based exploration. Funded by Ocean Networks Canada, the expedition supported seafloor mapping and ROV operations around five different observatory sites, as well as deployed and recovered numerous instruments as part of Ocean Networks Canada's annual maintenance (Figure 5). The expedition mapped over 3,811 square kilometers of seafloor and completed 20 successful ROV dives at depths between 370–2,700 meters that surveyed a wide diversity of deep-sea habitats.

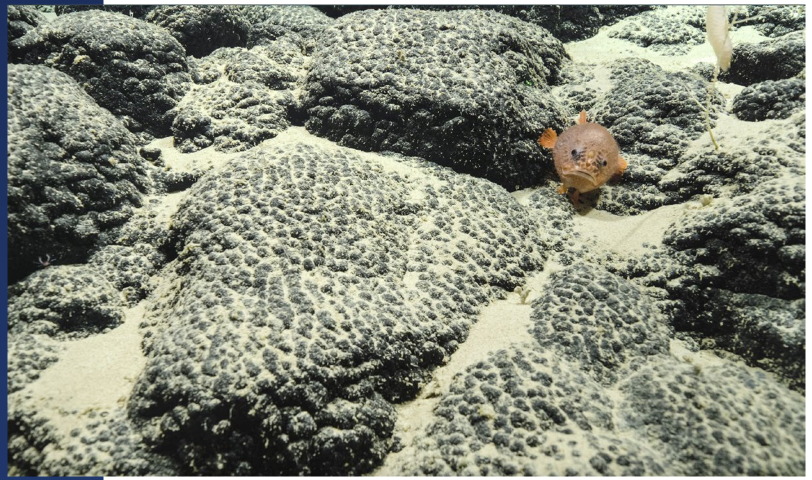
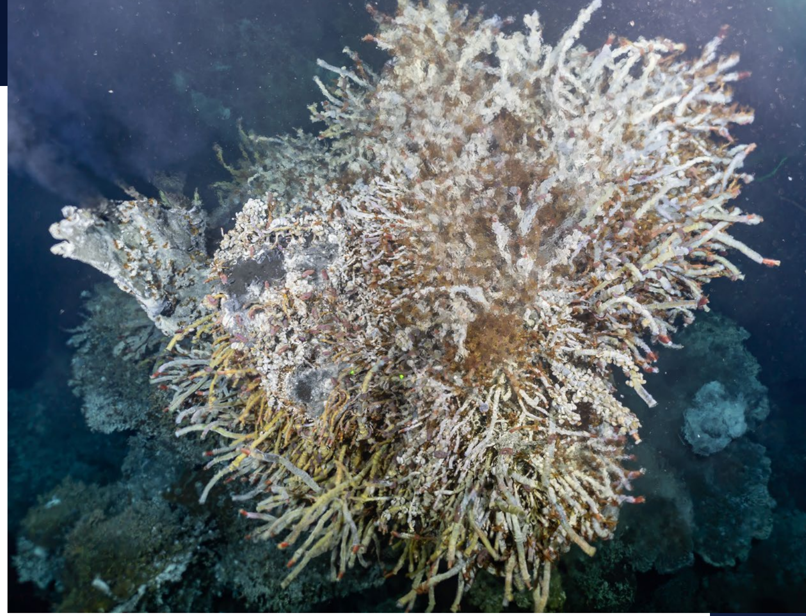


Figure 6. The 27-day expedition to Johnston explored the deep-sea biology and geology of seamounts located inside the Johnston Unit of the Pacific Remote Islands Marine National Monument.



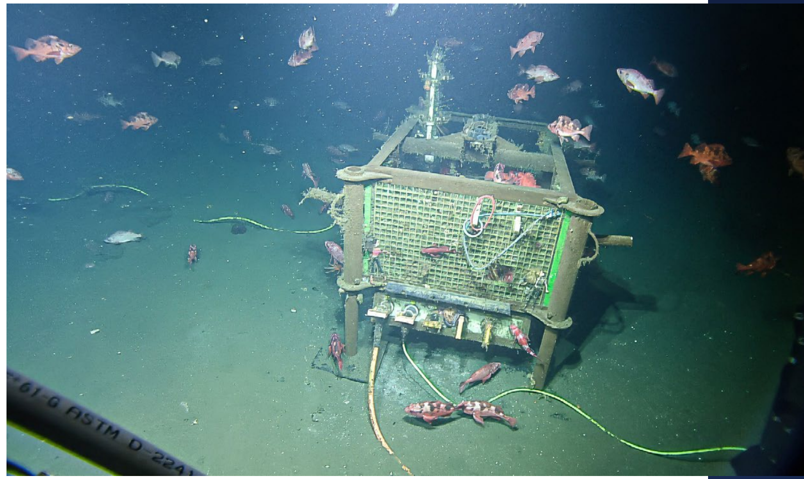


Figure 5. Marking the seventh year of a successful partnership between Ocean Networks Canada and OET, E/V *Nautilus* conducted a 21-day expedition that provided maintenance and support to the NEPTUNE cabled observatory off British Columbia.

JOHNSTON (NA153)

Between August 2–29, E/V *Nautilus* explored the deep-sea biology and geology surrounding Johnston Atoll (Figure 6). Funded by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, the expedition mapped over 32,259 square kilometers of seafloor and completed 11 successful ROV dives that explored depths between 1,000–3,200 meters. Noteworthy ROV observations included the first-ever record of a deep woodfall community in the US Pacific Remote Islands Marine National Monument, high-density coral gardens at nine different locations, evidence of extensive past lava flows at the summits of seamounts, and some observations of in-place reef outcrops. A total of 283 samples were collected during ROV dives to support ongoing studies on the deep-sea biodiversity, geological age, and volcanic history of the region.

PAPAHĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT (NA154)

Between September 1–28, E/V *Nautilus* explored the deep-sea natural and cultural resources in the northernmost and least explored section of the Papahānaumokuākea Marine National Monument. Funded by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, the expedition mapped over 23,466 square kilometers of seafloor, including five different seamounts. The expedition also completed 12 successful ROV dives to depths of 600–5,400 meters, which included the deepest dives ever conducted off E/V *Nautilus*. Expedition highlights included the discovery of one of the largest pink coral forests known, several high biodiversity communities (Figure 7), as well as comprehensive archaeological surveys of three historically-significant aircraft carriers lost during the Battle of Midway.

Figure 7. The 28-day Ala ʻAumoana Kai Uli expedition explored the northwesternmost section of the Papahānaumokuākea Marine National Monument, and included nine ROV dives focused on high biodiversity communities on seamounts.

Figure 8. The 2023 multi-vehicle expedition built on the success of the last two years and continued integrating emerging exploration technologies from partner institutions of the Ocean Exploration Cooperative Institute onto E/V *Nautilus* operations.

MULTI-VEHICLE EXPLORATION (NA155)

From October 1–19, E/V *Nautilus* conducted the third annual expedition focused on integrating emerging exploration technologies from partner institutions of the NOAA Ocean Exploration Cooperative Institute (Figure 8). Funded by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, the expedition combined the complementary exploration capabilities of uncrewed surface vehicle *DriX* from the University of New Hampshire, the autonomous underwater vehicle *Mesobot* from Woods Hole Oceanographic Institution, the Deep Autonomous Profiler from the University of Rhode Island, alongside E/V *Nautilus*' mapping capabilities. During 18 days at sea, these complementary technologies were used to explore the Geologists Seamounts, a poorly known group of seamounts located south of Hawaiʻi. Expedition highlights included over 425 hours of multi-vehicle operations, including periods when *DriX*, *Mesobot*, and the Deep Autonomous Profiler were all simultaneously deployed, while E/V *Nautilus* conducted independent mapping operations up to 37 kilometers away. Guided by data collected by the fisheries sonar on *DriX*, *Mesobot* was directed into specific portions of the water column to conduct targeted surveys, which recorded more midwater organisms and in more detail than ever before.

OCEAN EXPLORATION THROUGH ADVANCED IMAGING (NA156)

From October 22–November 5, E/V *Nautilus* surveyed some of the most complex deep-sea terrain around Hawaiʻi using a new wide-field camera and wideband multibeam sonar on ROV *Hercules*. During 14 days at sea, these technologies were used to gather high-resolution video and sonar data, as well as quickly develop high-fidelity models of the seafloor (Figure 9). Funded by the Office of Naval Research, the expedition completed 15 successful ROV dives that explored complex topographical features at 385–1,660 meter depths, including steep ridges, pinnacles, canyons, hydrothermal vents, and submarine wrecks from World War II. In addition to successfully integrating the new widefield camera, the expedition developed new protocols to increase the efficiency of seafloor exploration. Specifically, multibeam data collected during the ROV approach to the seafloor was used to develop detailed seafloor maps, and then precisely move the ROV towards areas of interest.

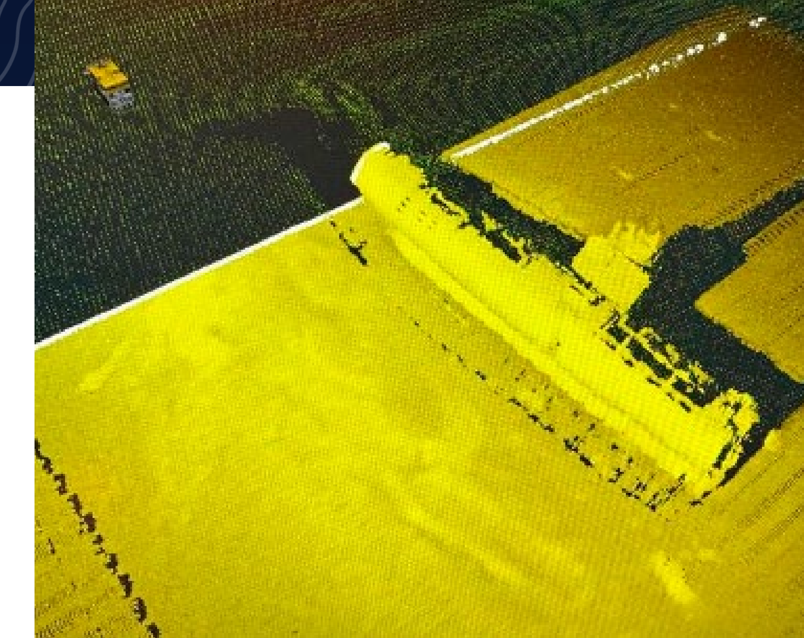


Figure 9. The 14-day Ocean Exploration through Advanced Imaging expedition focused on integrating a new widefield camera and wideband multibeam sonar onto ROV *Hercules* to build ultra-high resolution models of the seafloor, including two Japanese submarines from World War II scuttled off Oʻahu.

HAWAIʻI MAPPING (NA157)

From November 7–17, E/V *Nautilus* mapped offshore environments south of the Main Hawaiian Islands (Figure 10). Funded by NOAA Ocean Exploration and the Bureau of Ocean Energy Management via the Ocean Exploration Cooperative Institute, the expedition mapped over 5,911 square kilometers of seafloor and completed seven deployments of the Deep Autonomous Profiler Lander to maximum depths of 4,600 meters, during which continuous video, CTD environmental and passive acoustic data were collected for a combined time of 23 hours, in addition to 166 water samples for the study of eDNA, nutrients and particulate organic matter. In addition to surveying deep ocean environments, the expedition included topside surveys of seabird diversity and abundance, a first for E/V *Nautilus*.

Figure 10. The 10-day mapping expedition in the Main Hawaiian Islands was an interagency collaboration with NOAA, BOEM, and USGS (photo credit: Mark Mueller, BOEM).

JARVIS MAPPING (NA158)

From November 19–December 19, E/V *Nautilus* mapped deep seafloor around Jarvis Island (Figure 11). Funded by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, the expedition mapped over 40,445 square kilometers of seafloor, focused on data gaps in the Jarvis Unit of the Pacific Remote Islands Marine National Monument, as well as during transits to Honolulu. Dedicated mapping around Jarvis revealed numerous cratered seamounts, ridges and mounds.

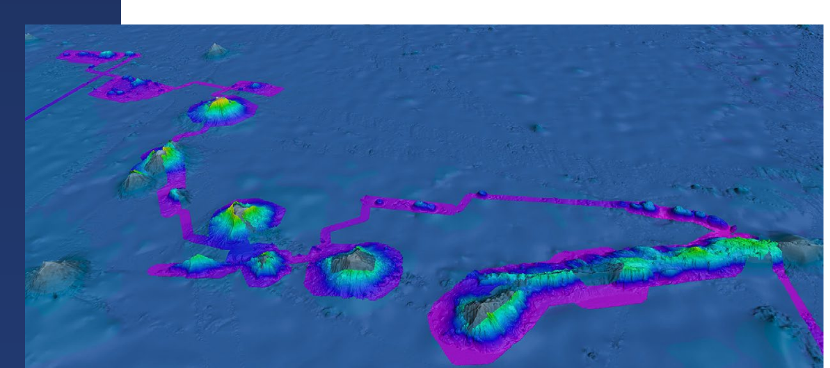


Figure 11. Dedicated mapping in the Jarvis Unit of the Pacific Remote Islands Marine National Monument revealed numerous cratered seamounts, ridges, and mounds. Image created with QPS Fledermaus software.

MAPPING HIGHLIGHTS
OF E/V *NAUTILUS* EXPEDITIONS IN 2023

Derek Sowers, Renato Kane, Lynette Davis, Kris Krasnosky, and Daniel Wagner

E/V *Nautilus* expeditions in 2023 relied on Honolulu as a central hub of operations, extending exploration efforts in all directions spanning from British Columbia to some of the most remote areas in the Central Pacific. Using its Kongsberg EM302 multibeam sonar and Knudsen 3260 sub-bottom profiler, E/V *Nautilus* mapped deep-water regions surrounding Palmyra Atoll, Kingman Reef, Johnston Atoll, Jarvis Island, the Hawaiian Islands, and off British Columbia. Collectively, 2023 expeditions mapped 183,474 square kilometers of seafloor, including 101,771 square kilometers in the US Exclusive Economic Zone of the Pacific Island Region. As is standard practice on E/V *Nautilus* expeditions, mapping operations were designed specifically to cover previously unmapped or poorly mapped seafloor, and thus contributed directly to the primary goals of the US National Strategy for Ocean Mapping, Exploration and Characterization, the Nippon Foundation-GEBCO Seabed 2030 Project, and the UN Decade of Ocean Science for Sustainable Development.

Mapping operations were conducted during four dedicated mapping expeditions, five remotely operated vehicle (ROV) expeditions, and on one multi-vehicle exploration mission. Prior to that, a dedicated mapping shakedown expedition was conducted at the beginning of the 2023 field season to calibrate and evaluate the performance of the EM302 multibeam sonar. This shakedown was also utilized to complete acceptance trials of the E/V *Nautilus*' new Kongsberg EC150-3C sonar, which was used throughout the field season as an acoustic Doppler current profiler to assess currents at ROV dive locations. A backscatter calibration of the EM302 multibeam sonar was also completed near O'ahu, with results supporting improved visualization of backscatter sonar data.

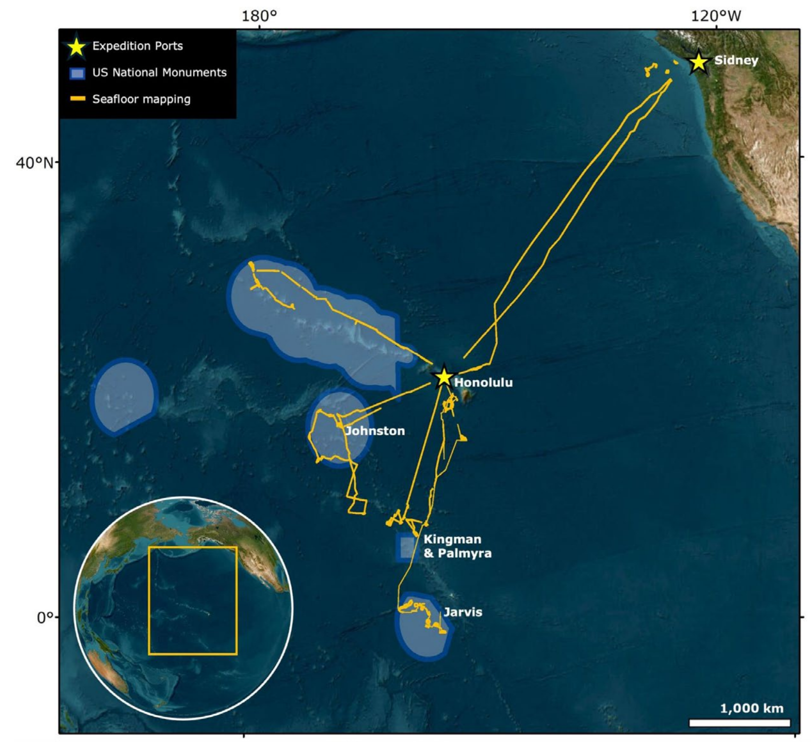
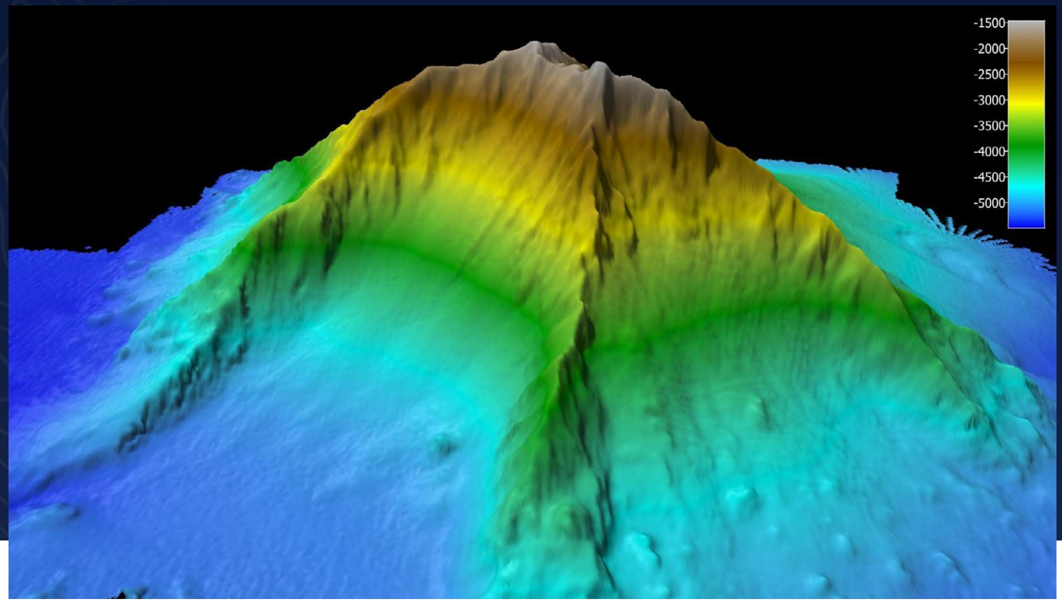


Figure 1. Map showing the locations of areas mapped using the acoustic mapping systems of E/V *Nautilus* during expeditions in 2023.

The first exploration mission of the year (NA149) focused on areas adjacent to the Kingman/Palmyra Unit of the Pacific Remote Islands Marine National Monument (PRIMNM). Over 24,095 square kilometers of seafloor were mapped over the course of the expedition, including 13,124 square kilometers inside the US Exclusive Economic Zone. Seafloor mapping focused on filling data gaps north of the Kingman/Palmyra Monument Unit, and partially mapping ten different seamounts. The next three expeditions (NA150, NA151, and NA152) entailed transiting between Hawai'i and British Columbia, as well as completing maintenance and instrumentation replacements on the cabled NEPTUNE observatory operated by Ocean Networks Canada. Over 51,283 square kilometers of seafloor were mapped during these three missions, including portions of the Mendocino, Pioneer and Murray fracture zones, as well as several unnamed seamounts. The fifth exploration expedition (NA153) was completed in the vicinity of the Johnston Atoll Unit of PRIMNM, and included a large course diversion to avoid Hurricane Dora. A total of 32,259 square kilometers of seafloor were mapped over the course of the expedition, including 17,318 square kilometers inside PRIMNM. The second half of the field season began with the Ala 'Aumoana Kai Uli expedition to the Papahānaumokuākea Marine National Monument (NA154). Seafloor mapping focused on filling data gaps in the northwestern section of the Monument and during transits to Honolulu. A total of 23,466 square kilometers of seafloor were mapped over the course of the expedition, including 21,972 square kilometers inside the Monument. This included filling the remaining mapping gaps over five different seamounts, including one at the northwestern end of the Monument that was mapped in its entirety by E/V *Nautilus* (Figure 2).

Figure 2. Three-dimensional perspective view of the unnamed seamount mapped during the Ala 'Aumoana Kai Uli expedition in the northwestern region of Papahānaumokuākea Marine National Monument (NA154). The color ramp represents depths in meters. Image created with QPS Fledermaus software.



The next expedition focused on integrating multiple exploration technologies from partner institutions of the NOAA Ocean Exploration Cooperative Institute (NA155), with opportunistic mapping of 5,719 square kilometers of seafloor using E/V *Nautilus*' sonars near the Geologists Seamounts. The eighth expedition of 2023 (NA156) focused on using advanced imaging systems on ROVs to explore complex underwater terrain around Hawai'i. A highlight of this expedition was using the Norbit wideband multibeam sonar mounted on ROV *Hercules* in combination with K2Mapping acquisition software to produce ultra-high-resolution seafloor maps. These ultra-high resolution maps were produced in real time and thereby allowed the team to locate targets of interest and precisely move the ROVs towards them (Figure 3).

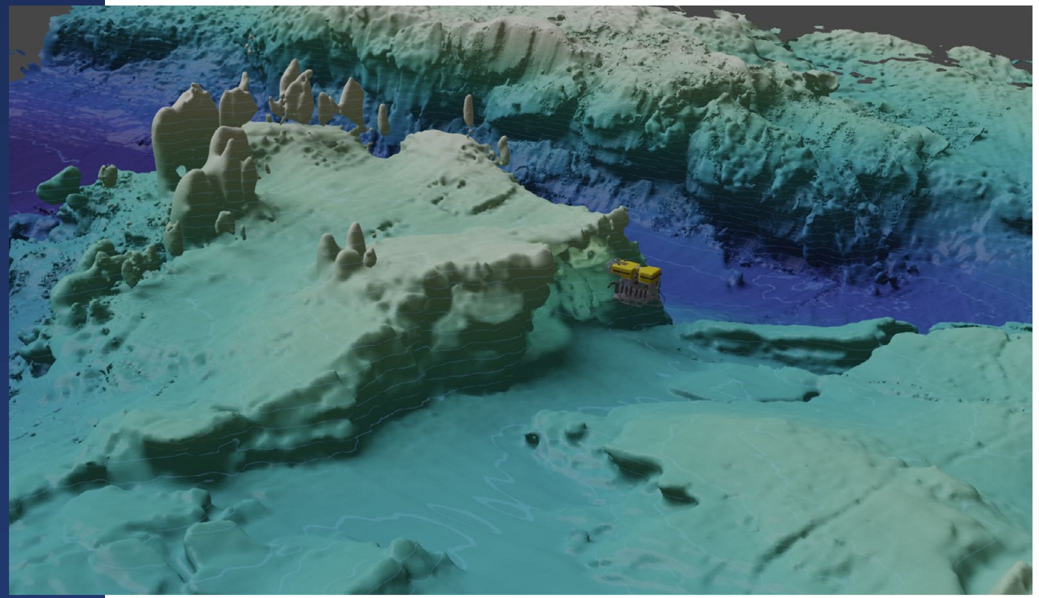


Figure 3. Three-dimensional rendering of bathymetry acquired using the K2Mapping acquisition software and a Norbit multibeam mounted on the ROV visualized with a model of ROV *Hercules* as it explores a vertical wall (image credit: Kris Krasnosky, Seaward Science).

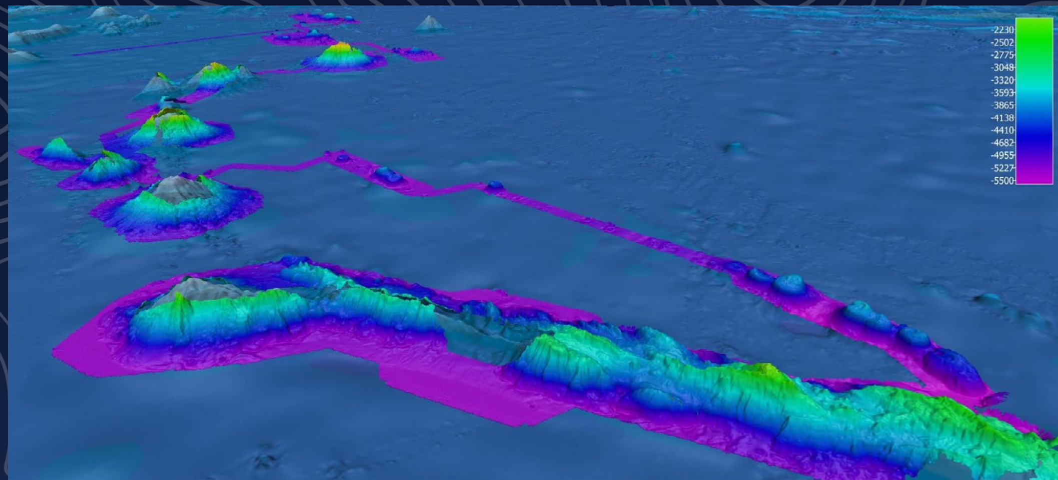


Figure 4. Three-dimensional perspective view of ridges and seamounts mapped within the Jarvis Unit of PRIMNM during NA158. The tops of some of the seamounts in this region had previously been mapped and were thus not remapped on this expedition. The color ramp represents depths in meters. Image created with QPS Fledermaus software.

The mapping work completed on the next expedition of the 2023 season (NA157) was jointly supported by the Bureau of Ocean Energy Management and NOAA, and included seafloor mapping of 5,911 square kilometers around the Geologists Seamounts. The final expedition of the 2023 season (NA158) was a dedicated mapping mission to survey unmapped portions of the Jarvis Unit of PRIMNM. Seafloor mapping focused on filling data gaps located northwest and east of Jarvis Island, with over 40,445 square kilometers of seafloor mapped over the course of the expedition, including 19,549 square kilometers inside PRIMNM. Seafloor mapping on this mission revealed numerous fascinating cratered seamounts, ridges and mounds in the Jarvis Unit of PRIMNM (Figure 4).

In addition to mapping previously unsurveyed seafloor, 2023 expeditions continued to train the next generation of mappers, hydrographers and explorers. A total of nine seafloor mapping interns sailed on 2023 expeditions, during which they stood science watches and were trained on all aspects relating to acquiring and processing mapping data (Figure 5).

As in previous years, mapping data collected during 2023 expeditions were submitted to the Rolling Deck to Repository, the Marine Geoscience Data System, the Global Multi-Resolution Topography data synthesis, and the GEBCO Seabed 2030 data centers, and thereby provide a publicly-accessible foundation to stimulate future explorations throughout the Pacific.

Figure 5. Seafloor mapping intern Daveenah Guise (left) on the radio and ready to deploy an expendable bathythermograph probe to support mapping operations. Seafloor mapping intern Casidhe Mahuka (right) processing multibeam sonar data.

DRIX OPERATIONS FROM E/V *NAUTILUS*

Larry Mayer, Val Schmidt, Roland Arsenault, Basile Rose, Andy McLeod, Avery Munoz, K.G. Fairbarn, Jenna Ehnot, Natalie Cook, Nina Yang, Annette Govindarajan, Dana R. Yoerger, and Eric Hayden

The 2023 season saw major upgrades and successes for *DriX*, the uncrewed surface vessel that is an integral part of the NOAA Ocean Exploration Cooperative Institute's efforts to develop advanced technologies in support of ocean exploration. The 7.7-meter long vehicle with its unique wave-piercing composite hull, was first integrated onto E/V *Nautilus* in 2022, and quickly demonstrated its value by serving as a communications link and command center for several other uncrewed vehicles, including Woods Hole Oceanographic Institution's *Mesobot* and *Nereid Under Ice* (NUI). This coordinated use of multiple vehicles enabled the exploration of the seafloor, midwater and sea surface all at once, a critical step in advancing the efficiency of ocean exploration. Most excitingly, through the communications protocols and collaborative behaviors developed in 2022, we were able to develop a new approach to survey midwater habitats, a strategy we call verified directed sampling. This strategy takes advantage of the fact that we can see water column targets from the *DriX* sonar systems in real-time, and then precisely direct midwater vehicles like *Mesobot* to the target and turn imaging or sampling systems on or off. In 2022, *Drix* also demonstrated its ability to collect high-quality bathymetry in shallow waters, thereby freeing up the ship to carry out independent activities and expand the exploration footprint.

As the 2023 season began, the University of New Hampshire *DriX* team, in collaboration with engineers from Exail Technologies, undertook some major upgrades to *DriX* to help it better serve the needs of the NOAA Ocean Exploration Cooperative Institute. First among these upgrades was the change from a shallow-water multibeam sonar (Kongsberg EM2040; maximum depth 500 meters) to a sonar capable of mapping in much deeper water (a Kongsberg EM712), which we hoped could map to maximum depths of 3,000 meters. This change represented a major challenge, as the standard EM712 had large rack-mounted topside electronics that would not fit in the slim body of *DriX*, and the EM712 transducers were much larger than the original *DriX* gondola. Through tremendous collaboration between the manufacturers, Kongsberg designed a new EM712

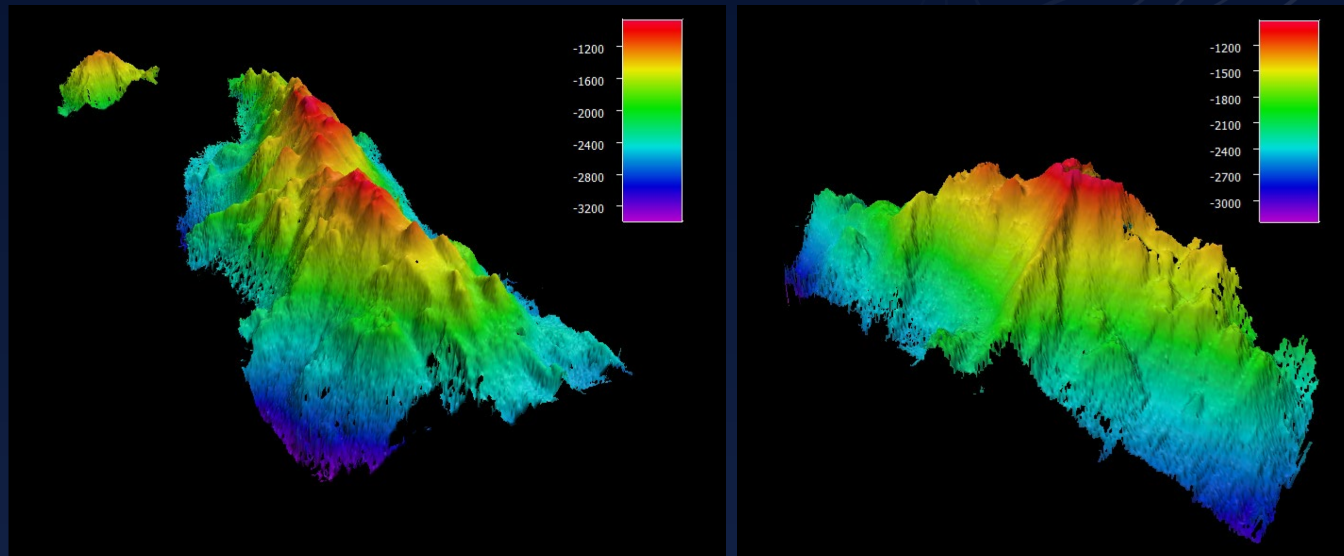


Figure 2. McCall (left) and Washington Seamount (right) as mapped with the EM712 on *DriX*. The color ramp represents depths in meters.

USV system, which brought most of the topside components into a compact subsea compartment, co-located with the transducers in the gondola. To accommodate this new design, Exail designed a new gondola that was almost double in size and weight than the original one, as well as made many modifications to the mast and hull of *DriX* (Figure 1). These extensive modifications occurred over just five weeks while *DriX* was at the University of Hawai'i Marine Center before the start of the 2023 E/V *Nautilus* field season.

Figure 1. New gondola installed on *DriX* along with StarLink antenna on small black mast at the aft end of the vehicle. Sketch of new *DriX* gondola with EM712 (inset).

The second major *DriX* upgrade made ahead of the 2023 field season was the installation of a StarLink satellite communication system to allow high-bandwidth communications with *DriX* anywhere in the world covered by StarLink. All these upgrades had their first sea tests during the 2023 shakedown expedition between April 24 and May 13 (NA147). Both systems performed well, but due to constraints of the operational area of the expedition, the EM712 could only be tested to maximum depths of 650 meters, and StarLink could only be tested in the vicinity of the island of O'ahu.

The true test of these systems came in October 2023 during the Technology Challenge Expedition (NA155) that combined the complementary exploration capabilities of *DriX*, *Mesobot*, and Deep Autonomous Profiler alongside E/V *Nautilus'* mapping capabilities. Having demonstrated the ability to do multi-vehicle work in 2022, this year we focused on enhancing our multi-vehicle capabilities to better understand the biodiversity around seamounts and answer important questions about sampling avoidance. Our work targeted McCall and Washington Seamounts, two of the Geologist Seamounts located approximately 280 kilometers south of Honolulu. Mapping of these seamounts with *DriX* demonstrated that the new EM712 worked beyond our expectations, mapping to depths deeper than 3,200 meters (Figure 2), albeit with a very narrow swath.

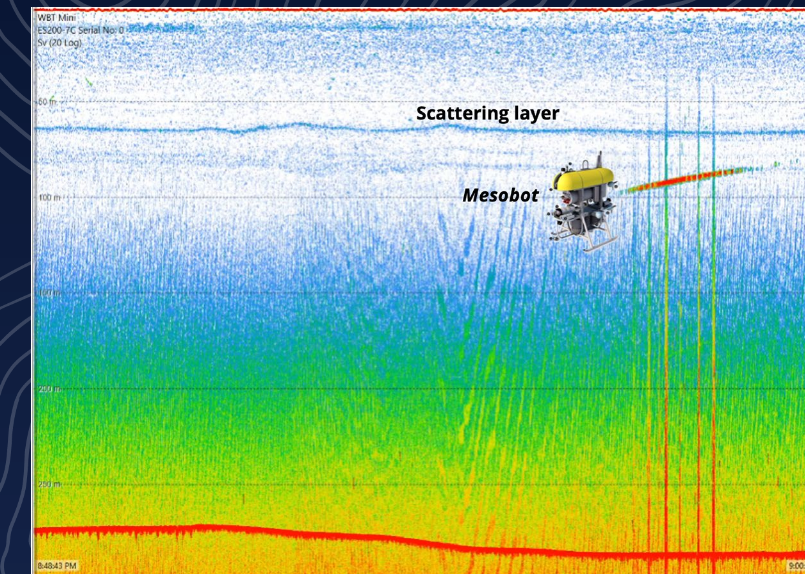


Figure 3. *Mesobot* being tracked along with target layer during verified directed sampling operation.

Our work around the seamounts took on several modes, exploring biodiversity as measured by our acoustic sensors and the systems of *Mesobot*, and experiments aimed at understanding sampling avoidance behavior of midwater organisms. The *DriX* and *Mesobot* teams worked collaboratively to enhance communication between both vehicles, as well as added new behaviors to answer these important scientific questions. We were able to send complex commands to *Mesobot* in order to dynamically change its sampling and imaging plans based on the observed reactions of midwater layers recorded by *DriX* (Figure 3).

An important new automated behavior developed during the expedition allowed *DriX* to follow a target layer but remain far enough away from *Mesobot*, so that *DriX* itself would not add to potential avoidance behavior of midwater organisms. Typically every 10 minutes, *DriX* crossed directly over *Mesobot*, verifying its exact location with respect to the target midwater layer (Figure 4). As *DriX* and *Mesobot* worked collaboratively, the StarLink communications system was put to the test as E/V *Nautilus* moved away from the vehicles to map in deeper water. The vehicles worked as far away as 37 kilometers from E/V *Nautilus* while maintaining full communications and data transmission. Carrying our over-the-horizon tests one step further, a team sitting at the University of New Hampshire was able to take full control and operate *DriX* from a remote operating center in New Hampshire (Figure 5). This successful demonstration of long-range capabilities bodes well for next year's efforts, where we will attempt to run a shore-based *DriX* operation off American Samoa.

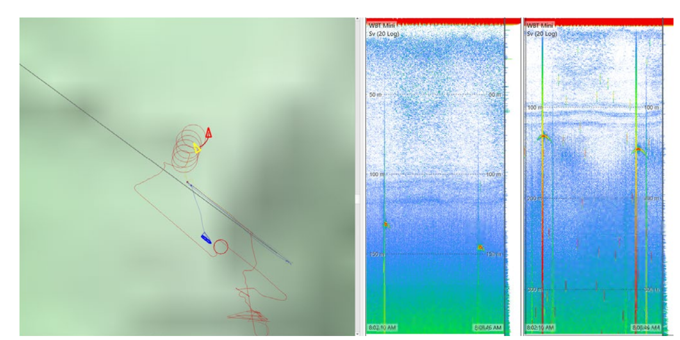
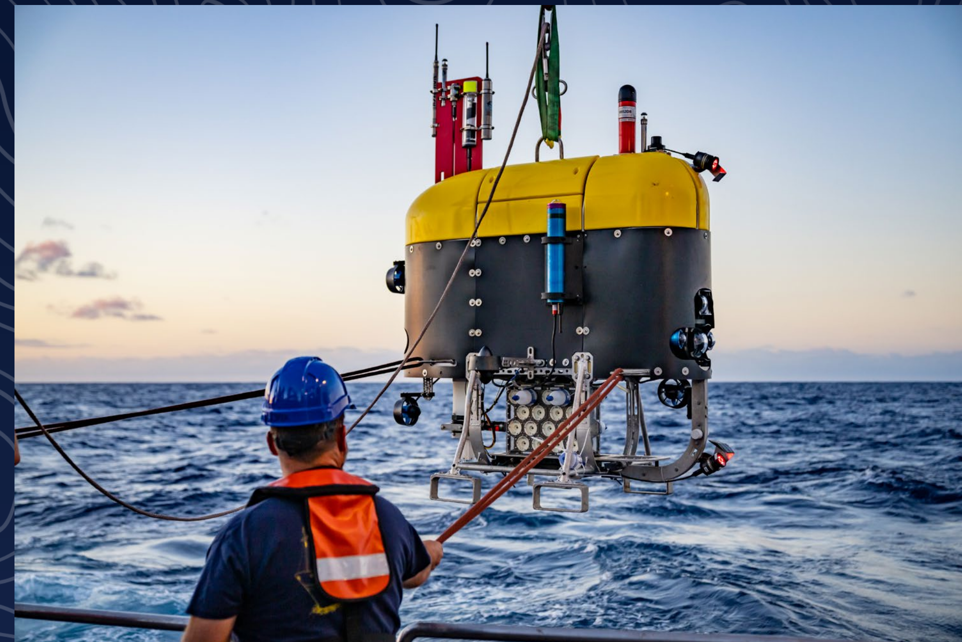


Figure 4. *DriX* automated behavior that followed *Mesobot* and continuously tracked the subsurface layer, but only passed directly over *Mesobot* every 10 minutes. Red points on the right side of the figure show the verified position of the midwater layer being sampled.

Figure 5. University of New Hampshire team operating *DriX* remotely from the university campus in Durham.



MESOBOT:

MIDWATER BIODIVERSITY EXPLORATION IN COLLABORATION WITH *DRIX*

Eric Hayden, Dana R. Yoerger, M. Jordan Stanway, Larry Mayer, Val Schmidt, Annette Govindarajan, and Nina Yang

OVERVIEW

During the 2023 Multi-Vehicle Exploration Expedition (NA155), *Mesobot* explored midwater environments over the Geologist Seamounts, a poorly known group of seamounts located southwest of the Big Island of Hawai'i. Funded by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, the expedition deployed *Mesobot* 19 times, with most of its dives focusing on the water columns above McCall and Washington Seamounts at depths down to 850 meters (Figure 1). On each dive, *Mesobot* collected continuous environmental data with its radiometer, optical backscatter, fluorometer, CTD, and dissolved oxygen sensors. In addition to these standard sensors, *Mesobot* was equipped with two new instruments, a multi-camera system and a set of eDNA multisamplers. These systems are *Mesobot*'s primary methods of surveying biological activity, and can be used to sample both independently, or in collaboration with uncrewed surface vehicle *DriX* as directed in real time (see Mayer et al., in this report). On the NA155 expedition, we used the verified directed sampling technique that we developed last year and refined it through the use of new video collection and eDNA sampling methods. Other upgrades implemented during NA155 included equipping *Mesobot* with a new automatic information system (AIS) beacon, and adding a direct Wi-Fi connection between *Mesobot* and *DriX*. These upgrades allowed for interactions between the two vehicles to continue even after *Mesobot* came to the surface or when E/V *Nautilus* was outside Wi-Fi range, which proved highly valuable.

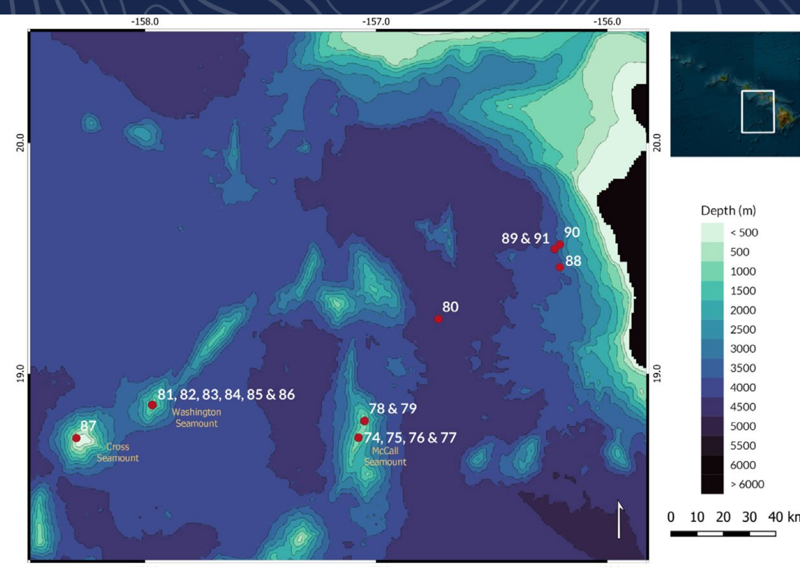


Figure 1. Deployment locations of *Mesobot* during the 2023 Multi-Vehicle Exploration Expedition (NA155).

eDNA SAMPLING

Mesobot was deployed with two eDNA multisampler units, giving it the capacity to collect 32 samples per dive (see Govindarajan et al., in this report). As a highly mobile and precisely-controlled sampling platform, *Mesobot* was able to conduct different sampling strategies. In core sampling routines, *Mesobot* followed a pre-programmed script to collect samples autonomously at predetermined depths, whereas in experimental sampling *Mesobot* was directed to different target depths based on real-time data collected by the EK80 midwater sonar on *DriX*. Using these different approaches, *Mesobot* collected a total of 186 eDNA samples over the course of the NA155 expedition.

VIDEO SURVEYS

With two new cameras and new survey strategies, *Mesobot* captured many hours of remarkable footage of midwater biodiversity. *Mesobot*'s previous science camera was replaced with a more capable and operator-friendly Z CAM E2-M4. This camera was controlled by both mission scripts and by remote acoustic commands, capturing high-definition video with the equivalent of a typical videography lens. The second new *Mesobot* camera, the DSPL DigiSeaCam, was used previously by colleagues at Woods Hole Oceanographic Institution. Mounted directly above the Z CAM, this camera captured events with less sensitivity and in slightly lower quality, but with a field of view twice as large as the Z CAM. The two cameras complemented each other well, allowing the team to begin by reviewing the wide angle DigiSeaCam video to get a general picture, and then use the Z CAM footage to focus in on specific details.

Equally important to the success of our video surveys was modifying our strategy in obtaining that video. In past expeditions, we had recorded video while driving *Mesobot* forward along transects, as is done in midwater transects conducted by ROVs. The reasoning behind this strategy is that we should see more organisms by covering more ground. On this expedition, however, we also employed a different imaging strategy, during which *Mesobot* held depth and drifted with the current. *Mesobot* has the ability to hold depth with precision better than 1 centimeter using steady, minimal thrust. This method, which has been used with Human Occupied Vehicles dating back to Beebe & Barton in the *Bathysphere*, proved immediately effective. Within seconds of *Mesobot* settling into position, small organisms such as worms, krill, and salps emerged from the surrounding waters into the well-lit area in front of the cameras.

The variety of small species was found to be very different depending on the dive location. For example, at McCall Seamount, *Mesobot* recorded a large number of salps, while at Washington Seamount, the video was dominated by clouds of krill. Likely in response to the presence of these smaller organisms, *Mesobot* recorded a variety of mesopelagic fish and some larger predators such as an oceanic whitetip shark and a broadbill swordfish.

Figure 2. *Mesobot* team members Dana R. Yoerger and M. Jordan Stanway communicate with the vehicle from the control van onboard E/V *Nautilus*.

Schools of squid, likely attracted to *Mesobot*'s lights, were a common sighting throughout the expedition, even at the surface during recovery.

While any survey strategy will be biased, as lights, vehicle motion, and acoustic emissions will attract some animals while repelling others, we found that the hovering strategy was more effective at documenting midwater biodiversity. Using this hovering strategy, we recorded more types of animals in a given setting than when driving the vehicle forward. Furthermore, while hovering we saw little or no disturbance of the field of animals, particles, and even squid ink trails.

MULTI-VEHICLE COLLABORATION

In addition to informing eDNA sampling locations, target depths for video collection and eDNA sampling were often informed by real-time data from *DriX*'s EK80 midwater echosounder, as viewed by our collaborators on E/V *Nautilus* or ashore. In the past we had only used verified directed sampling for eDNA sampling, so this was a new application of the verified directed sampling strategy. In addition to expanding the verified directed sampling technique, we also improved *Mesobot*'s ability to interact with *DriX* on the surface. Previously, when *Mesobot* rose to the surface at the end of a dive, *DriX* was moved a longer, more conservative distance away to wait until the ship could safely recover *Mesobot*. With no way to communicate with *Mesobot* in air, *DriX* could do no more than avoid colliding with *Mesobot* until the ship's arrival. On this expedition, however, *Mesobot* was equipped with a new AIS beacon and a Wi-Fi connection with *DriX*. The new beacon let *DriX* know when and where *Mesobot* surfaced, as soon as the acoustic tracking was lost. As the surface location was periodically updated, *DriX* could maintain a radius around *Mesobot*, within Wi-Fi range. This allowed the team aboard E/V *Nautilus* to communicate with *Mesobot* through *DriX* while the ship was still far away. An example of this was when *Mesobot* surfaced unexpectedly during one of its dives, while E/V *Nautilus* had already moved away to conduct other operations. *DriX* maintained close proximity to *Mesobot* so that engineers aboard E/V *Nautilus* could immediately begin diagnosing the problem over Wi-Fi. Previously, this would have had to wait until *Mesobot* was secured back on deck, or at least until the ship had returned to Wi-Fi range (about 150 meters). Thanks to these recent upgrades, however, the problem was diagnosed quickly, and *Mesobot* was commanded to dive again to continue its mission, all controlled remotely from E/V *Nautilus*. This greatly improved operational efficiency and situational awareness.

Figure 3. The deck team recovering *Mesobot* at night during the NA155 expedition.

CONCLUSION

While there were many accomplishments and lessons learned during the NA155 expedition, we are still in the process of analyzing the large datasets collected by *Mesobot* on this mission, particularly the video. Once complete, we will link the *Mesobot*'s observations to those made by *DriX* and E/V *Nautilus*, and thereby provide a comprehensive view of the midwater environments explored during NA155.

DEEP AUTONOMOUS PROFILER (DAP) OPERATIONS OFF E/V *NAUTILUS*

Chris Roman and David Casagrande

The Deep Autonomous Profiler (DAP) is a hadal instrument that was developed by the University of Rhode Island to survey the deepest portions of the world's oceans. Rated to 11-kilometer depth, the DAP is a lander and water column profiler that is capable of collecting environmental data (i.e., temperature, salinity, oxygen, density, and sound), recording video segments, and collecting water samples throughout the water column, or while resting on the seafloor. The instrument is built around a 24-bottle Seabird CTD rosette, and is operated by a custom electronics package (Figure 1). The DAP can operate for approximately 24 hours, depending on the camera configuration, making it a flexible platform for joint operations with other vehicles.

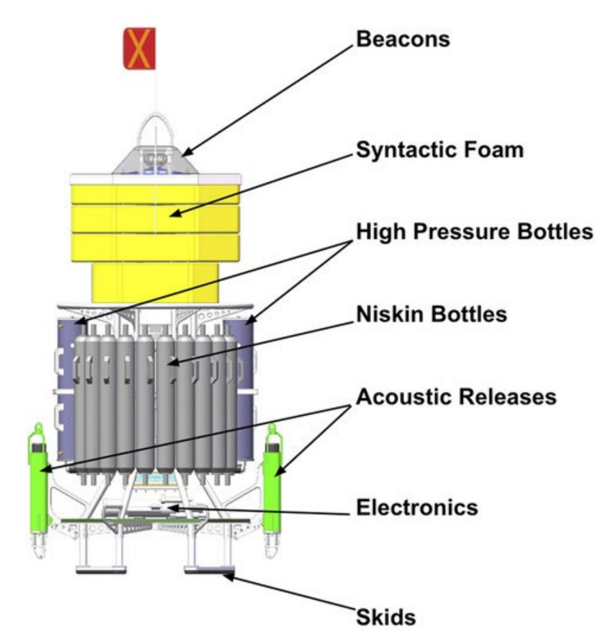


Figure 1. Schematic of the Deep Autonomous Profiler (DAP) showing the location of key elements.

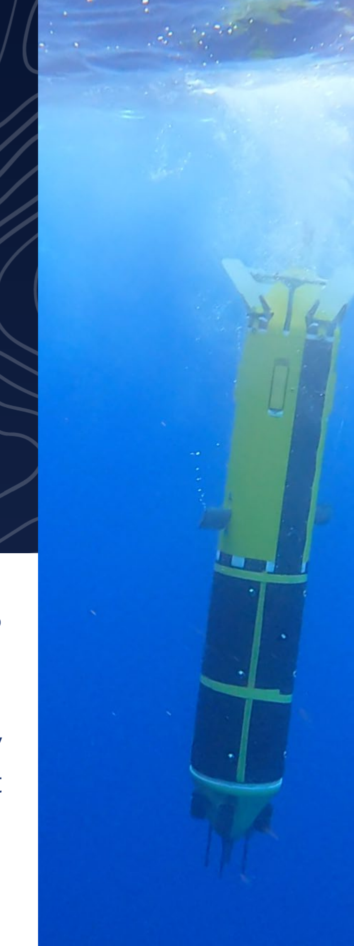
The DAP was used on two expeditions during the 2023 E/V *Nautilus* season (NA155 and NA157; Figure 2). On both missions, water was collected for eDNA analysis using its 12-liter sample bottles. The water collection depths were generally pre-programmed to cover the water column. The DAP is also capable of sampling features of interest in a targeted manner via artificial intelligence. The user can define a parameter of interest (i.e., temperature, salinity, oxygen, density) and a specific value or gradient for that parameter. An algorithm will then process data from the down cast to select the appropriate sample depths for the up profile. This alleviates the need to have all sample depths prescribed prior to deployments.

Figure 2. The Deep Autonomous Profiler (DAP) being deployed from E/V *Nautilus* during the NA157 expedition.

A 6,000-meter rated acoustic recorder (Ocean Sonics SC60-ETH icListen) was also integrated into the DAP to collect passive acoustic data over a wide frequency range (10 hertz–200 kilohertz), and thereby provide insights into the behavior of marine animals (e.g., whale vocalizations, fish sounds, snapping shrimp), natural abiotic sounds (e.g., wind, volcanic activity), and anthropogenic impacts (e.g., shipping activity). The recorder can be set to run for timed intervals, or record continuously using power provided by the vehicle. During 2023 deployments, the recorder was used to document the sound of E/V *Nautilus*' multibeam sonar. For this purpose, the ship intentionally drove over the position of the DAP on the seafloor in order to make recordings that could help better characterize the sonar.

Once deployed, the DAP can be tracked using the E/V *Nautilus* ultra-short baseline (USBL) navigation system, which provides accurate bottom locations and confirmation of the instrument's ascent or descent through the water column. This is helpful for ground truthing the actual bottom type at a known location with the DAP camera system. The camera lighting requires significant power, and is run off a dedicated Deep Sea Power and Light SeaBattery. This provides power for about 2.5 hours of continuous imaging, which can be programmed to occur at particular times, or run on a repeating cycle such as 10 minutes on followed by 20 minutes off.

During recovery, two global position system (GPS) beacons relay the position of the DAP while on the surface. In general, the timing of the DAP deployments and recoveries were well coordinated with other operations, thereby making the instrument a valuable addition to joint operations with other vehicles. Building on the 12 successful DAP deployments conducted during the 2023 field season, we look forward to deploying the instrument on future E/V *Nautilus* expeditions in 2024 and beyond.



HADAL WATER COLUMN PROFILER

OPERATIONS OFF E/V *NAUTILUS*

Glenn S. Carter, Jeff C. Drazen, Chris I. Measures, Blue Eisen, Bruce M. Howe, and Stanley Lio

Ocean trenches, also known as the hadal zone, span 45% of our ocean's total depth range and collectively cover a seafloor area that is about the size of Texas. Due to their remoteness and inaccessibility, trenches represent by far the least explored parts of our ocean. To address this knowledge gap, the University of Hawaiʻi at Mānoa developed the Hadal Water Column Profiler with funding from the W. M. Keck Foundation. Rated to 11-kilometer depth, the instrument is capable of recording surface to seafloor vertical profiles of temperature, conductivity (salinity), dissolved oxygen, turbulent mixing, current velocity, 200 kHz acoustic backscatter, video, as well as is able to collect small water samples for the study of trace metals.

The Hadal Water Column Profiler is 4 meters long, 0.54 meters in diameter, and weighs 570 kilograms in air. Ballast weights are used to make the instrument sink and fall freely towards the seafloor (Figure 1). Once the ballast is released at a user-defined height above the seafloor as measured by an altimeter, the profiler becomes positively buoyant and returns to the surface. For flotation the instrument uses Isofloat® foam, from Ron Allum Deepsea Services, glass microspheres in a carbon fiber reinforced epoxy resin. There are two independent Seabird temperature and conductivity systems, and dissolved oxygen is measured by two Aanderaa Optodes. The turbulent microstucture component was custom made by Rockland Scientific International. The Hadal Water Column Profiler uses a geo-electromagnetic current meter, designed by the Applied Physics Laboratory of the University of Washington, that measures the voltage generated by the motion of seawater through the Earth's magnetic field to produce a vertical profile of horizontal current velocities. The trace metal water sampler collects up to 11 water samples (150 milliliters each). The profiler also has a DeepSea Power & Light Nano SeaCam video camera and two LED lights to observe water column plankton, as well as a sideways looking 200 kilohertz ASL Environmental Acoustic Zooplankton Fish Profiler. This frequency primarily detects zooplankton and larger crustaceans up to about 100 meters away from the instrument. To increase the signal-to-noise ratio in the current meter, the profiler rotates around its axis. This rotation leads to a trade-off between vertical resolution of the velocity data and the horizontal range of bioacoustic data.

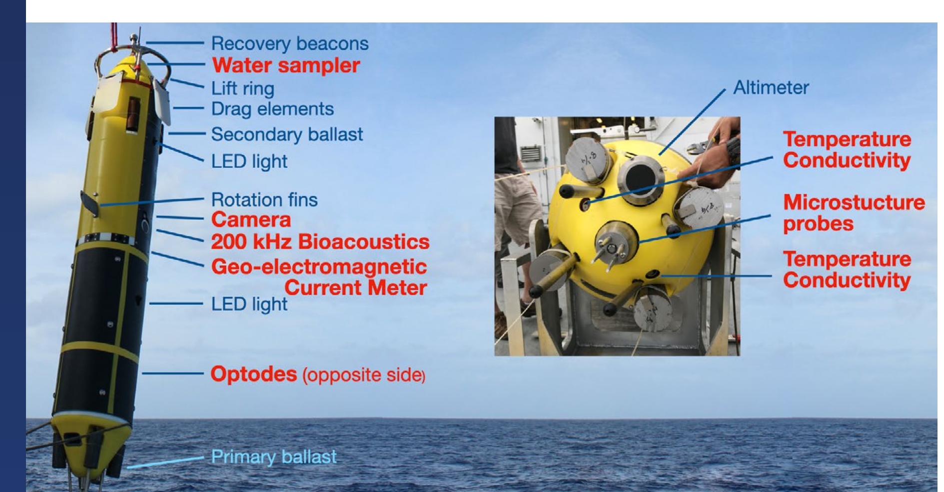


Figure 1. Location of key elements of the Hadal Water Column Profiler. Sensors producing scientific data are labeled in red.

Figure 2. The E/V *Nautilus* recovering the Hadal Water Column Profiler after a cast during the 2023 shakedown expedition (NA147).

During the 2023 E/V *Nautilus* shakedown expedition (NA147), we conducted at-sea testing of this new and unique instrument (Figure 2). Our goals of embarking on the expedition were to test sensor performance and improve the flight characteristics of the profiler. We conducted six test deployments to maximum depths of 2,575 meters, during which the physical sensors performed well. The video camera recorded siphonophores, fish and shrimp, and the bioacoustics sensor provided a vertical profile of backscatter that clearly showed a peak in biomass between 400- 700 meters, consistent with other studies in Hawaiʻi. With respect to flight characteristics, the principal goal of the expedition was to optimize the profiler descent and ascent rates. If these rates are too rapid, the quality of the sensor data degrades, particularly the acoustics and video data. Conversely, if these rates are too slow, deployments cannot be conducted quickly enough to collect meaningful data on tidal frequencies.

To minimize the chances of losing the instrument, the profiler has multiple pathways to release enough ballast to ascent to the surface. The primary ballast located at the bottom of the profiler, is set to release on a predetermined depth, fall rate, or elapsed time. It also has a purely mechanical corrosive link in case of power or mechanical failure of the release system. In case of a bottom impact in soft sediment, the profiler has a secondary set of ballast near the top of the profiler held on by a mechanical corrosive link. During the shakedown expedition we varied both sets of ballast weights and found a predictable relationship to descent and ascent speeds. We concluded that different amounts of ballast can be used depending upon mission goals. For instance, larger secondary weights can be used for slower ascents to focus on biological observations, whereas smaller ones can be used for faster ascents intended to investigate tides.

Data collected during the shakedown expedition provided key insights on how to fine tune the instrument for future scientific missions. Once fully operational, the Hadal Water Column Profiler will provide the means to substantially increase our understanding of one of the most poorly known ocean areas. Specifically, it will enable the first direct measurements of turbulent mixing in the deep ocean trenches, allow for simultaneous exploration of flow, trench ventilation, and midwater biological communities, as well as enable investigations of water layers above the seafloor with significant amounts of sediment, also known as nepheloid layers, which are likely widespread but poorly understood. Our partnership with the Ocean Exploration Trust and testing of the system on the E/V *Nautilus* have been a critical step in preparing the instrument for future scientific missions.

A PIONEERING DIVE IN OCEAN EXPLORATION:

FIRST-TIME ROV INTEGRATION OF THE LASER DIVEBOT RAMAN SPECTROMETER

Pablo Sobron

The 2023 E/V *Nautilus* expedition to Kingman Reef and Palmyra Atoll (NA149) marked the first time a remotely operated vehicle (ROV) used a high-tech laser for *in situ* sensing and analysis. This integration was part of the InVADER Laser Divebot mission, a collaboration between Impossible Sensing, SETI Institute, NASA Jet Propulsion Laboratory, University of Washington Applied Physics Laboratory, NOAA Ocean Exploration, and OET. The successful field deployment of the Laser Divebot represents a critical step towards performing real-time measurements without the need to collect physical samples, a paradigm shift for ocean exploration and research.

Originally developed for the study of distant ocean worlds like Europa and Enceladus, the Laser Divebot uses laser spectroscopy technology to also study our own ocean. The instrument can quickly and affordably analyze the chemical composition of seafloor features, including rocks, sediments, and organisms, without needing to stop. This means that the extent of data gathering is solely constrained by the speed of the vehicle, which facilitates missions surveying expansive areas. The 2023 mission was a success, with *in situ* data collected by the Laser Divebot on six ROV dives. Physical samples of objects surveyed with the Laser Divebot were also collected during the mission, which are being analyzed in the laboratory to help calibrate *in situ* measurements of the laser.

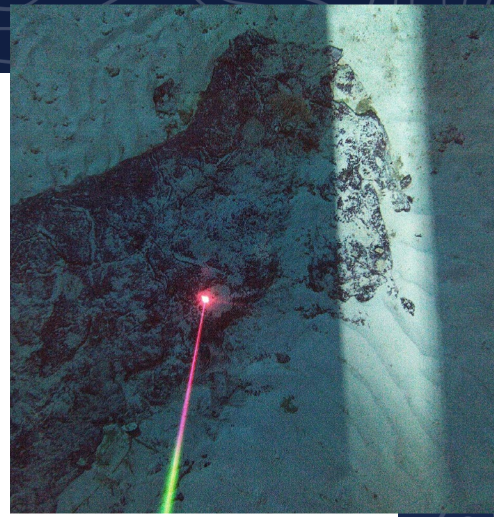


Figure 2. The Laser Divebot collecting *in situ* data on the chemical composition of the seafloor during an ROV dive on the NA149 expedition.

One of the instrument's most exciting features is its ability to characterize organic molecules on the seafloor, including bio-active compounds like pigments. Scientists can use this information to map the distribution of marine biodiversity. Moreover, the data gathered by the instrument provides geologists with valuable insights into the nature of marine minerals. Integrating mineral surveys with biodiversity studies presents an exciting opportunity to create comprehensive seafloor maps that can help inform conservation and resource management decisions.

The 2023 E/V *Nautilus* expedition provided important information to help refine the instrument for future ocean exploration missions. The InVADER team is planning to deploy the Laser Divebot on various geological formations and biological ecosystems in the Aleutian Islands, the Arctic, and the Gulf of Mexico.

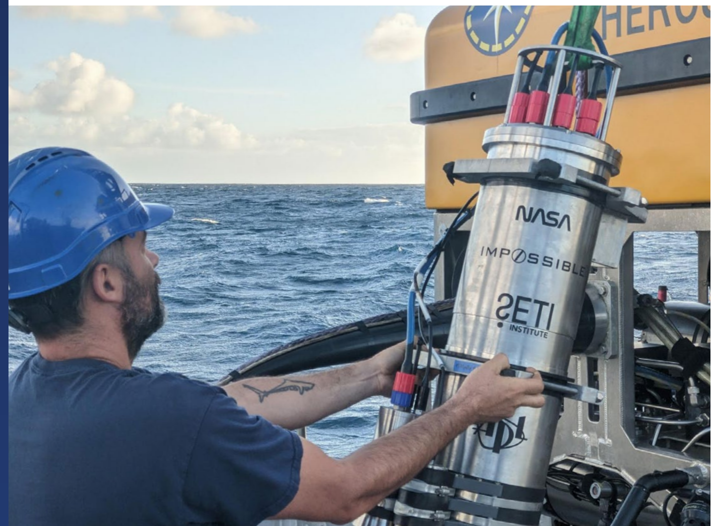


Figure 1. The Laser Divebot being integrated onto ROV *Hercules* prior to the E/V *Nautilus* expedition to Kingman Reef and Palmyra Atoll (NA149).

NEW TECHNOLOGY FOR IMMERSIVE IMAGING AND VISUALIZATION: WIDEFIELD CAMERA ARRAY

Jonathan Fiely, Jason Fahy, Robert D. Ballard, and Allison Fundis

Recent advancements in imaging and processing technologies have opened new possibilities for capturing and experiencing the environments we explore. Supported by the Office of Naval Research, Ocean Exploration Trust (OET) developed and tested an advanced imaging system for ROVs, named the Widefield Camera Array. Purpose-built to capture immersive, high-resolution cinematic footage of deep ocean discoveries, this system also creates high-fidelity reference imagery suitable for advanced three-dimensional modeling and simulation.

Rated to a depth of 6,000 meters (Figure 1), the system comprises three genlocked E2-F6 cinema cameras. Each camera features a 24-megapixel full-frame sensor capable of capturing images at 60 frames per second with a resolution of 6064×2560 pixels. Two cameras are configured to record stereoscopic images, providing a 180-degree field of view, while the third camera extends coverage by an additional 60-107 degrees. This setup enables the generation of 220-degree content ready for virtual reality, offering an unprecedented panoramic view of the underwater world.

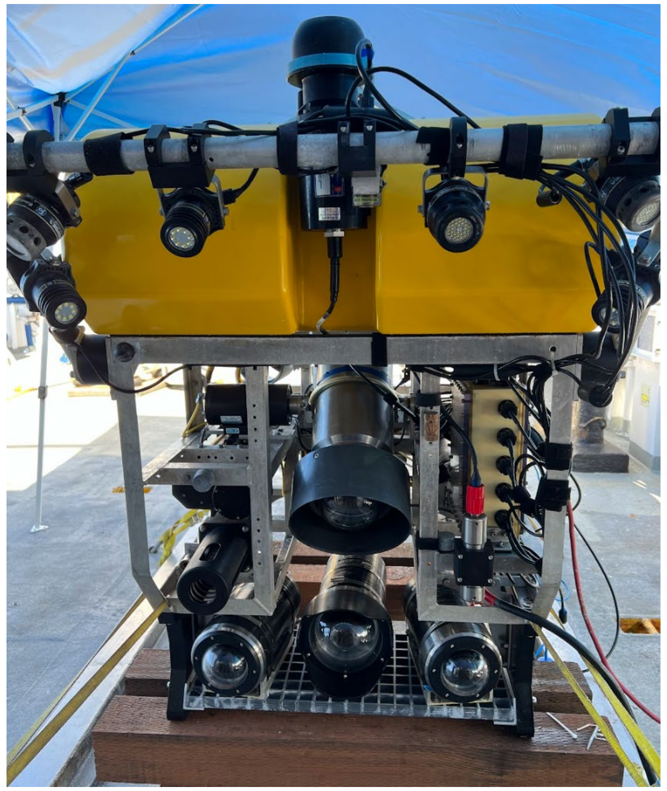


Figure 1. The Widefield Camera Array was designed to be deployable across OET's vehicles, including the 6,000-meter rated ROV *Little Hercules*.

Figure 2. The Widefield Camera Array operated in the control room of E/V *Nautilus* (left). Stereo cameras and the high-resolution camera mounted on the ROV operate in sync to acquire immersive imaging (right).

The technical innovation of the camera array lies in its ability to utilize the entire forward light pool generated by ROVs *Atalanta* and *Hercules*. Achieved by synchronizing the three cameras (Figure 2) to function cohesively with the ROV's other sensors, the two stereoscopic cameras enhance depth perception in surveyed areas. The third camera collects high-fidelity still images, calibrated alongside data from the ROV's NORBIT multibeam. These images are essential for creating accurate, georeferenced, and ultimately explorable three-dimensional models of the seafloor.

The Widefield Camera Array was tested during the Exploration Through Advanced Imaging expedition (NA156). Funded by the Office of Naval Research, the expedition was a field-testing ground for the system, demonstrating its capability to deliver high-fidelity, cinematic immersive imaging, and testing edge-based image processing for further development (see Fahy et al., in this report). Throughout the expedition, the camera collected over 8.5 terrabytes of high-resolution video and photo. These files were transferred in near-real time during dives for edge-based processing on the ship (Figure 3) prior to being sent ashore.

The Widefield Camera Array marks a significant advancement in imaging technology, providing a promising new capability for future ocean explorations. Data collected with the system prepared OET and our partners with the tools necessary to create photorealistic virtualized deep-sea environments, which allow the exploration of data and closely experiencing the deep sea in a realistic manner even after the ROVs have left the seafloor. With the increasing adoption of immersive experiences in science and education, this tool's potential to transform our exploration and understanding of the oceans is immense.

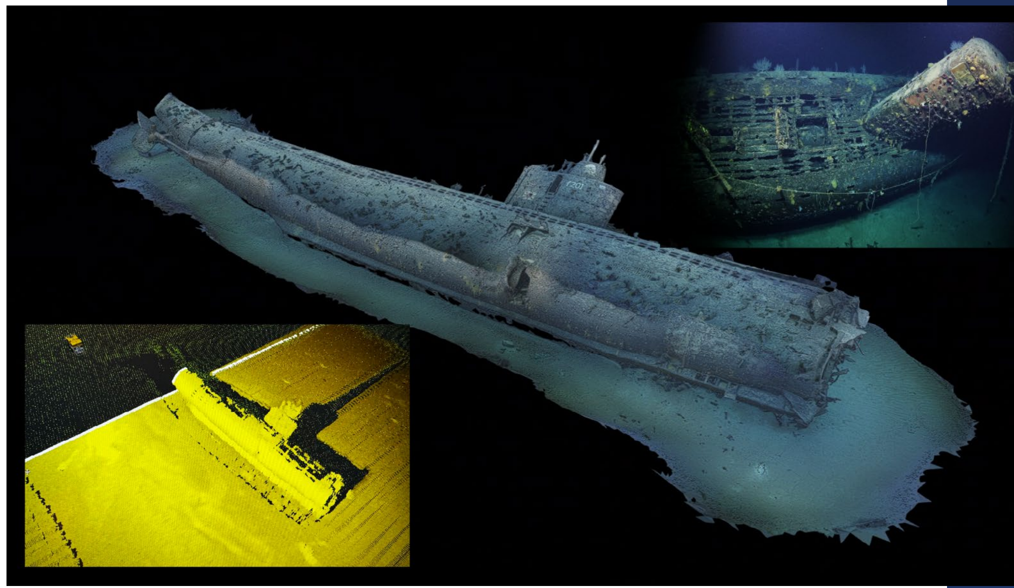


Figure 3. The Widefield Camera Array was used during the rapid immersive survey of the wreck of the Japanese submarine I-201. Three-dimensional scans of the submarine were generated in near real-time during the ROV survey. Ultra-high resolution multibeam data collected by the Norbit wideband multibeam sonar mounted on the ROV was used for model validation and further situational awareness.

EXPLORING DEEP-SEA CORAL COMMUNITIES IN THE CENTRAL PACIFIC WITH GENOME SKIMMING AND ENVIRONMENTAL DNA

Meredith V. Everett and Steven Auscavitch

Deep-sea corals and their wide diversity of associated species are an important contributor to global biodiversity. Currently there is limited understanding of the biodiversity, taxonomy and connectivity of deep-sea coral communities, particularly in remote areas like the Central Pacific. A more clear understanding of this information is important for the conservation of deep-sea coral communities, and is also relevant to the management of marine conservation areas throughout the region, including the Papahānaumokuākea Marine National Monument and the Pacific Remote Islands Marine National Monument.

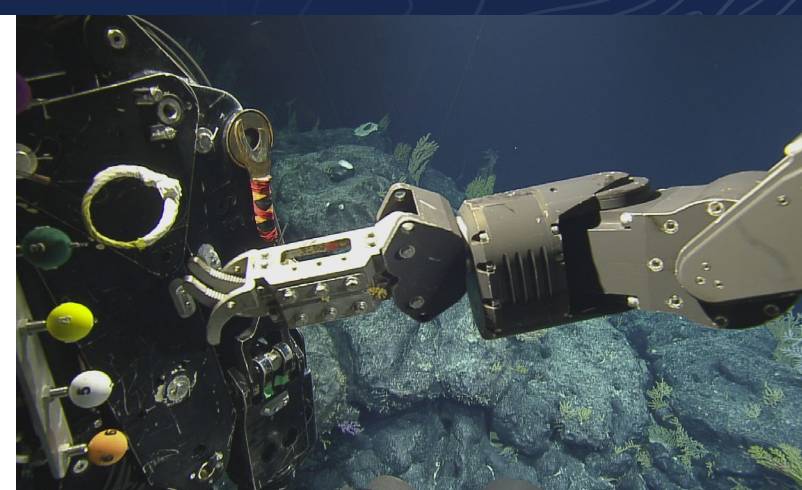


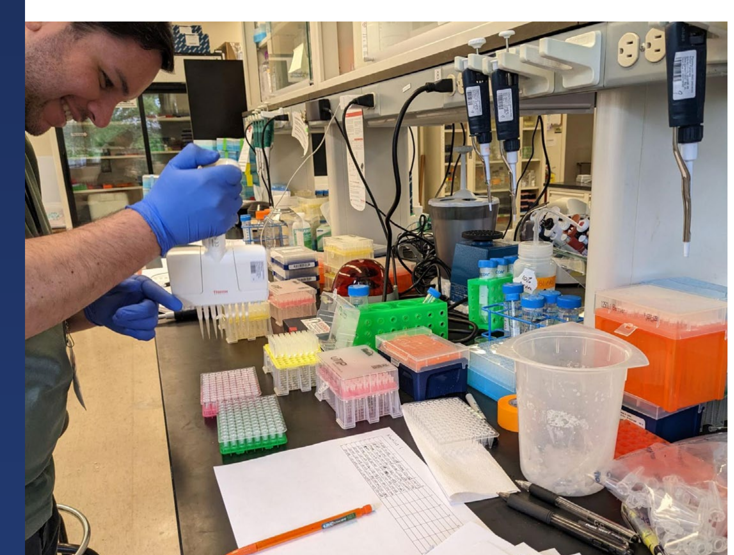
Figure 1. ROV *Hercules* triggering a Niskin bottle mounted on the ROV, thereby collecting a water sample near a deep-sea coral community for the study of eDNA.

Environmental DNA (eDNA) based methods can help address these knowledge gaps, as they provide rapid ways to characterize biodiversity, while only requiring minimally invasive water sampling. In addition to biodiversity characterizations, there are many practical applications to the use of eDNA, including the detection and monitoring of species that are of interest to resource management, such as endangered, invasive, or fisheries species. Such eDNA-based approaches can be particularly powerful for the study of difficult to access places like the deep sea, as they have the potential to provide large amounts of information without requiring much time collecting samples. However, success in this space hinges on the ability to collect physical samples that can be paired with detailed imagery whenever possible, so that the detected eDNA can be compared against well-curated reference libraries. Expeditions onboard E/V *Nautilus* provide rare and important opportunities to advance this work.

Figure 2. University of Rhode Island graduate student Jane Carrick retrieving an eDNA water sample from the Niskin bottle mounted on ROV *Hercules* (photo credit: Steve Auscavitch).

Since 2018 our team has collaborated with the Ocean Exploration Trust to collect eDNA samples and vouchered deep-sea coral specimens on E/V *Nautilus* expeditions across the Central Pacific (Figures 1–2). With support from NOAA Ocean Exploration, we are using these samples to build the first voucher library explicitly targeting octocorals of the Central Pacific. In support of this effort, we are utilizing 170 deep-sea coral samples collected during E/V *Nautilus* expeditions, in addition to octocoral samples collected by other programs that are archived at National Museum of Natural History, Smithsonian Institution. These samples have been subjected to genome skimming using Illumina NovaSeq and HiSeq platforms, a novel sequencing approach that provides insights on biodiversity and evolutionary history at lower costs than traditional methods (Figure 3).

Analyzing these data we have been able to produce 251 novel, draft mitochondrial genomes, and extracted 247 complete sequences of MutS, a DNA repair protein that is useful for studies of evolutionary history and biodiversity of different organisms. These have been combined with previously generated and publicly available MutS sequences to generate an eDNA reference library for octocorals in the Central Pacific. These data represent more than 52 genera within 21 families of deep-sea corals, and include a number of new species that are currently in the process of being described.



Future efforts will include additional analyses to determine the genetic relationships of these species to other octocorals, as well as metabarcoding eDNA samples collected across the Central Pacific. Between 2018–2022, we have obtained 226 eDNA samples from nine separate E/V *Nautilus* expeditions, with 85 additional samples added from three expeditions in 2023. While metabarcoding of these eDNA samples is ongoing, initial tests applying an early version of our updated DNA voucher library have shown promising results, with the ability to detect more species and an increase in the ability to distinguish species. Once data collection is complete, we will apply these data to better characterize patterns of octocoral community biodiversity by geography and habitat variables. Finally, we will compare community structure by geography to better understand patterns of connectivity or dispersal barriers to species distribution.

Figure 3. Steve Auscavitch preparing coral samples collected by E/V *Nautilus* for genome skimming at the Genetics Laboratory of the NOAA Northwest Fisheries Science Center.

EXPLORING BIODIVERSITY WITH ENVIRONMENTAL DNA

USING DIVERSE OCEAN EXPLORATION PLATFORMS AND SAMPLING STRATEGIES

Annette Govindarajan, Nina Yang, Miranda Holland, Eric Hayden, Dana R. Yoerger, Larry Mayer, Val Schmidt, Chris Roman, and David Casagrande

A key goal of the 2023 Multi-Vehicle Exploration Expedition (NA155) was to explore the Geologists Seamount region using new environmental DNA (eDNA) strategies, work that was supported by NOAA Ocean Exploration. Towards that end, we collected a total of 248 eDNA samples using different technologies (*Mesobot*, *DriX*, and the Deep Autonomous Profiler) deployed during the expedition (Figure 1). Laboratory processing of these samples at the Woods Hole Oceanographic Institution is now in progress.

The ocean's midwater environment, ranging from the surface to the seafloor, is the largest habitat on Earth and is home to a myriad of animal species with diverse behaviors, life histories, and ecosystem functions. Many of these species are poorly studied or unknown to science. Analysis of eDNA is a forensic approach for biodiversity exploration, and includes identifying animals based on the trace genetic signatures that they leave behind via sloughed cells, fecal pellets, and other mechanisms. Diverse eDNA sampling strategies that utilize a variety of technologies will maximize the biodiversity information that can be gained, as well as its environmental context. Importantly, animals and their eDNA are not distributed uniformly throughout the midwater habitat. Thus, adaptive strategies that respond to sensor data such as acoustic backscatter may be especially useful for efficient and informative sampling.

Our eDNA sampling strategy during the NA155 expedition was accordingly multi-faceted. Our core missions entailed obtaining samples from a range

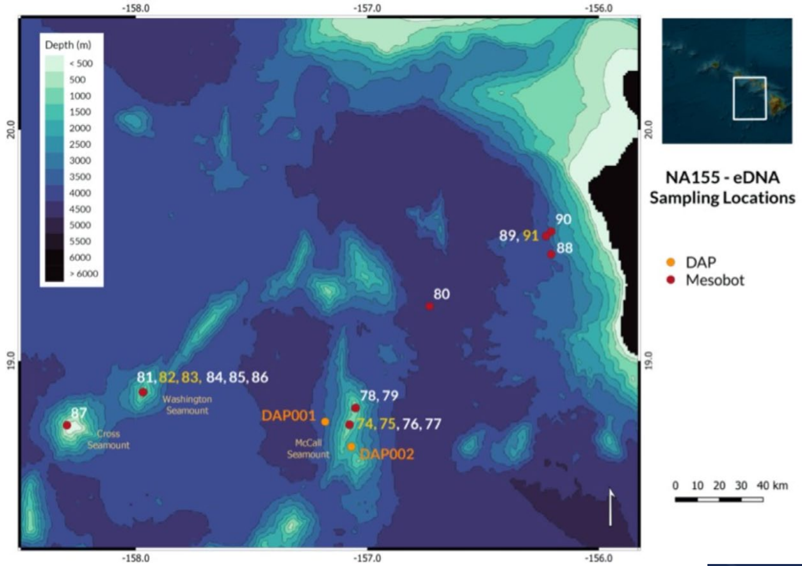
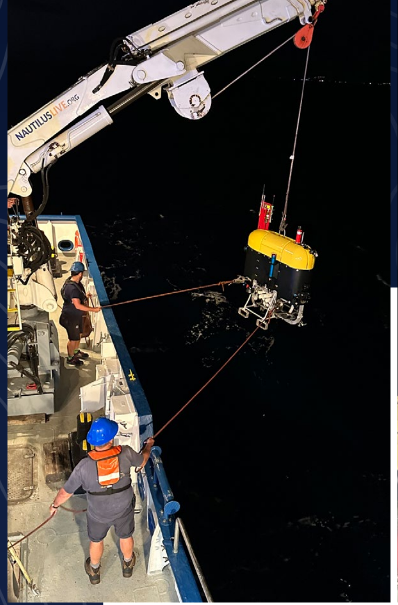


Figure 1. Map of eDNA sampling locations. *Mesobot* core sampling deployment numbers are in yellow font; *Mesobot* experimental deployment numbers are in white font, and Deep Autonomous Profiler sampling deployments are in orange font.

of depths along vertical transects running from the surface to about 1,000 meters. Sampling was conducted during both the day and the night, to account for distributional shifts associated with diel vertical migration, a light-driven movement up and down the water column that many species undergo on a daily basis. In the most common pattern, migrating animals are found in shallower waters at night and in deeper depths during the day. Through the feeding and movement patterns of the migrating animals, diel vertical migrations expedite the movement of carbon from surface waters to the deep sea, so is an important component of the biological carbon pump. Sampling on the core dives was conducted using large volume eDNA multisamplers that were recently developed by Oceanic Labs and the Woods Hole Oceanographic Institution and mounted on *Mesobot* (Figure 2). Duplicate samples were collected at each of eight different depths (20, 50, 100, 150, 200, 400, 600, and 800 meters) by filtering seawater for 20 minutes onto large-area capsule filters, resulting in filtration volumes of over 40 liters per sample. We have previously found that sampling large volumes enables the detection of more taxa. We conducted day and night core sampling at McCall Seamount, Washington Seamount, and off of the leeward side of Hawai'i Island (Figure 1).



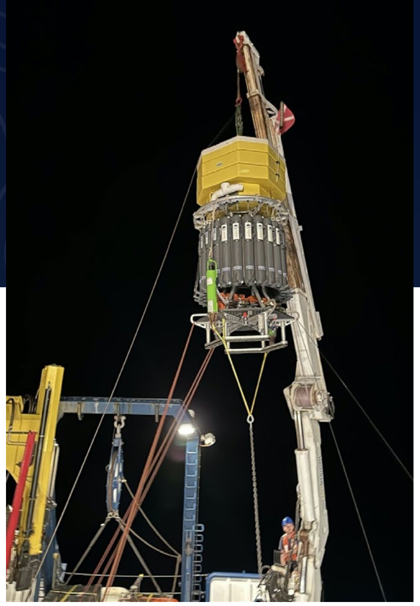


Figure 2. The E/V *Nautilus* deck team recovering *Mesobot* after a successful deployment that collected eDNA samples (left). The eDNA samplers are located in the payload area at the base of the vehicle.

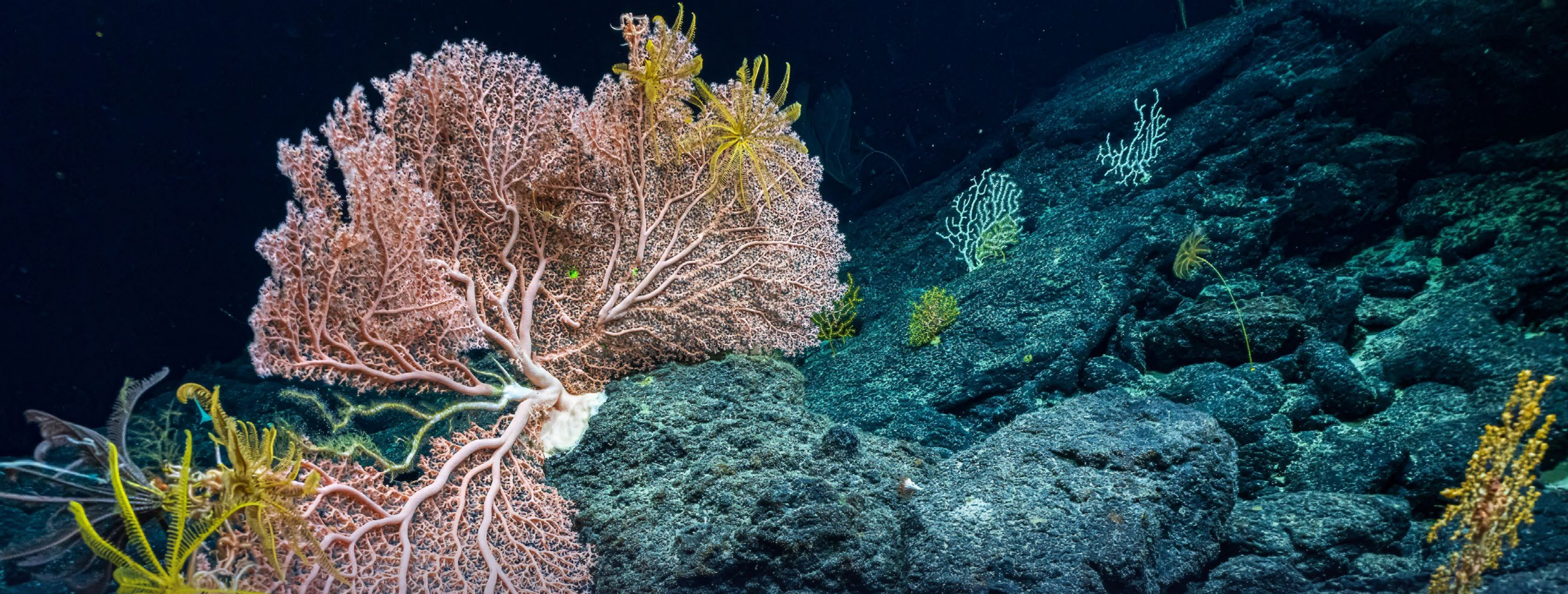
Figure 3. View of the Niskin bottles that collected water for eDNA samples on the Deep Autonomous Profiler (right).

In addition to core sampling, we also conducted several experimental missions with *Mesobot* in conjunction with University of New Hampshire's uncrewed surface vehicle *DriX*, using a multi-vehicle adaptive sampling approach termed verified directed sampling (see Mayer et al., in this report). In this approach, *DriX* obtained acoustic backscatter data reflecting concentrations of biomass. This information was then used by ship or shore-based scientists to determine where *Mesobot* should collect eDNA samples. The scientists relayed this information to *DriX*, which then communicated with *Mesobot* to direct it to travel to the target depth and sample. *Mesobot*'s movements were confirmed or verified by *DriX*. In one of our verified directed sampling deployments, shore-based personnel at Woods Hole Oceanographic Institution communicated with the team onboard E/V *Nautilus* to make sampling decisions. The successful integration of these vehicles and the ability to participate in sampling decisions from shore via telepresence technology are important steps towards advancing ocean exploration.

Additionally, several experimental missions utilized a *Mesobot* sampling strategy that entailed baiting with light. Normally, *Mesobot*'s lights are turned off during sampling to avoid biasing the results by altering the distribution of animals which may be attracted to the light—and subsequently the distribution of their eDNA. By intentionally leaving the lights on, our goal was to attract animals that might not have been detected otherwise. This strategy assumes that animals release detectable amounts of eDNA over the course of *Mesobot*'s time at the sampling depth, which is something we will assess when we analyze our results. Additionally, our eDNA results will be compared to video that was simultaneously captured by *Mesobot*.

Lastly, we also conducted eDNA sampling with the Deep Autonomous Profiler during the NA155 expedition (Figure 3). This instrument is equipped with Niskin bottles, which collected water from pre-determined depths from the surface to the seafloor at maximum depths of 4,000 meters (see Roman and Casagrande in this report). Once the Deep Autonomous Profiler was back on board the ship, the water from the Niskin bottles was immediately filtered with peristaltic pumps to collect eDNA (Figure 4). This sampling strategy entailed sample collection spanning the entire water column so that depths below the twilight zone, all the way to the bottom could be collected—complementing our twilight zone sample sets from *Mesobot*.

Figure 4. In the E/V *Nautilus* wet lab, we filtered seawater from the Deep Autonomous Profiler to collect eDNA samples.



EXPLORING DEEP-SEA HABITATS NEAR KINGMAN REEF AND PALMYRA ATOLL

Brian RC Kennedy, Adam Soule, Lila Ardor Bellucci, Giuliana Fillion, Sara Vahdatshoar, Coralie Rodriguez, Deborah Smith, Dwight Coleman, and Daniel Wagner

There have been several previous efforts to explore the deep sea around Kingman Reef and Palmyra Atoll, including expeditions by the Hawai'i Undersea Research Laboratory in 2005, NOAA Ship *Okeanos Explorer* in 2017, R/V *Falkor* in 2017, and E/V *Nautilus* in 2019 and 2022. However, most of these historic efforts focused on the 50 nautical miles around the islands that are part of the Pacific Remote Islands Marine National Monument (PRIMNM), leaving the remaining areas in the US Exclusive Economic Zone (EEZ) around Kingman and Palmyra virtually unexplored. Funded by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, the 2023 E/V *Nautilus* expedition to these remote islands (NA149) sought to explore some of these deep-water areas for the first time using the ship's mapping and ROV systems. Throughout the planning and execution of the mission, the team worked closely with the science and resource management community to ensure that expedition activities addressed priority needs, including the Monument Management Plan currently in development, and the proposed designation of the area as a National Marine Sanctuary.

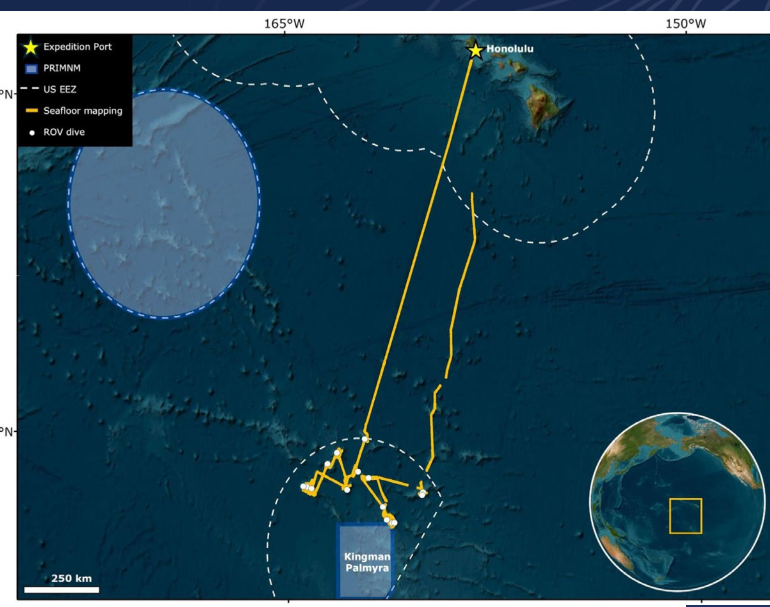


Figure 1. Map showing the locations of seafloor mapping operations and ROV dives conducted during the NA149 expedition.

Expedition mapping operations focused on unmapped seamounts northeast of the Kingman Reef and Palmyra Atoll, including mapping data collected at planned dive sites and in transit. Over 24,095 square kilometers of seafloor were mapped over the course of the expedition, including 13,124 square kilometers inside the US EEZ around Kingman and Palmyra (Figure 1). These maps revealed unexpected seafloor complexity on numerous seamounts, and were key to planning ROV dives over these areas.

The expedition completed 16 successful ROV dives at depths ranging from 1,087 to 3,111 meters, exploring ten previously unsurveyed seamounts (Figure 1). Noteworthy observations included high-density coral gardens (Figure 2), new species of jellies, and fossilized whale bones, among others. Overall, hundreds of species were documented (Figure 3–4), including several potentially undescribed species and several range extensions. A total of 95 biological, 59 geological, and 38 eDNA water samples were collected to support ongoing studies of the region's deep-sea biodiversity, geological age, and volcanic history. In addition to exploring previously unsurveyed areas, six ROV dives included the first-time integration of the Laser Divebot Raman and fluorescence spectrometer. *In situ* data collected by the spectrometer will be compared to lab-based analyses of collected samples, and thereby help develop important new tools for ocean exploration (see Sobron in this report).

Figure 2. One of the high-density coral communities documented during the NA149 expedition. This one hosted a very diverse set of animals including several families of corals and sponges.

Noteworthy ROV observations included two individuals of *Bathykorus sp.* jellyfish, along with the second-ever collection of an undescribed corallivorous jelly. Although this species has been documented throughout the Central Pacific, the previous inability to collect a specimen has obstructed formal identification. Similarly, bone-eating worms resembling the infamous *Osedax* were collected. Preliminary field identifications by biologists aboard E/V *Nautilus* are in the process of being verified by taxonomic experts. If indeed verified to be *Osedax* species, this would represent a significant range extension given that the nearest record of these worms is off California. The expedition also documented three high-density coral communities, two dominated by bamboo corals and one by a diversity of different coral groups. These observations mark the first documented high-density coral communities in the region outside the Monument boundaries.

A diversity of rock types were recovered across ten seamounts and will help illuminate the geologic history of the northern Line Islands region.

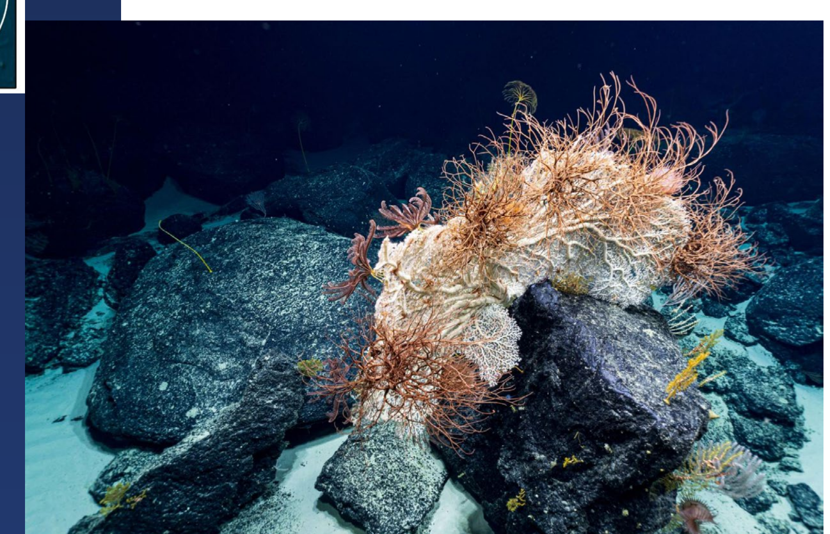


Figure 3. Deep-sea corals are considered ecosystems engineers and this photo is a demonstration of that concept. The coral is providing structure that several other animals are taking advantage of to get better access to the faster currents found above the seafloor.

Figure 4. This *Poliopogon* sponge has an unusual growth form. The brown hairy looking parts anchor the sponge to the seafloor, while the white tops are where food collection takes place.

Nearly all of the geological samples contained ferromanganese crusts, which are known to concentrate rare metals. Kingman and Palmyra lay at the intersection of several regions of the Pacific that are hypothesized to contain some of the richest accumulation of these resources, making understanding the geology and biology of the area particularly important given discussions about deep-sea mining. Basalt samples ranged from highly altered to unaltered, and displayed a range of vesicularity that may reveal their original depth of eruption. Sedimentary rocks, including volcaniclastic deposits and cemented breccias of basalt and carbonate, were recovered on the lower slopes of seamounts. On the seamount summits, uplift exposed sedimentary rocks that formed in the lagoons of the former atolls. During dive H1764, ROV *Hercules* explored features on top of a guyot that may be potential remnants of the channel between two prehistoric islands that would have ringed an atoll when the summit was above sea level (Figure 5).

Additionally, the team documented four fossilized skull fragments of beaked whales that were coated with ferromanganese crusts, indicating their ancient age. These samples can help us understand the water chemistry through the analysis of their crusts and provide insights about the evolution of beaked whales through examination of the fossilized remains. One melon-sized pumice sample was also recovered, which presumably drifted a long distance on the sea surface from its eruption site before settling to the seafloor in this remote region. The geological samples collected provide insight into the formation and geological history of the surveyed region, vital to our understanding of the area and consideration for Sanctuary designation.

Upon completion of the expedition in mid June 2023, expedition footage reached over 9 million viewers through the web and social media, whereas early expedition results were featured in 142 media stories published in 27 different countries and in 15 different languages. Three science communication fellows, five science and engineering interns, and three additional students participated in the expedition, gaining various interdisciplinary skills in sample collection and preservation, back deck operations, seafloor mapping, and scientific communication. Public outreach at an international level was paramount throughout the expedition, as operations were shared through live ship-to-shore broadcasts with classrooms and public events, promotion of expedition content on the web and on social media, and live streaming of expedition footage.

Figure 5. During dive H1764, ROV *Hercules* explored a very complex set of carbonate cliffs that could possibly have been the channel between two islands in an atoll complex many millions of years ago.

2023 OCEAN NETWORKS CANADA EXPEDITION
ABOARD E/V *NAUTILUS*

Meghan Paulson, Fabio De Leo, Dirk Brussow, A.J. Baron, Lauren Hudson, Dorothy Eggenberger, Yuko Lin, Katie Shoemaker, and Robyn Meyer

Continuous ocean monitoring is critical to detecting changes in our dynamic ocean, as well as better understanding its role in mitigating climate change. In summer 2023, Ocean Networks Canada (ONC), an initiative of the University of Victoria, and the Ocean Exploration Trust (OET) embarked on a 22-day expedition (NA151; June 25–July 18, 2023) aboard E/V *Nautilus* to provide maintenance of ONC's NEPTUNE observatory. Located off the west coast of Canada, the observatory consists of an 800-kilometer loop of fiber optic cable that connects numerous instruments across five sites, thereby providing high-resolution temporal observations not afforded by traditional ship-based exploration. The expedition completed 20 successful remotely operated vehicle (ROV) dives for routine maintenance, including the deployment and recovery of observatory instruments, as well as benthic and mid-water surveys (Figure 1). A total of 114 samples were collected to support ongoing temporal studies on ocean processes across ONC's observatory sites, including water samples and sediment cores. Additionally, the expedition mapped 3,811 square kilometers of seafloor in priority areas for marine protection identified by Fisheries and Ocean Canada. The expedition marked the seventh year of a successful partnership between ONC and OET.

Figure 1. Map showing the location of ROV dives and seafloor mapping operations conducted during the NA151 expedition aboard E/V *Nautilus*.

Figure 2. An Endeavour hydrothermal vent located at a depth of 2,200 meters.

Figure 3. *Ridgeia piscesae* tubeworms documented on a hydrothermal vent.

SMOKE AND MIRRORS

Endeavour may be the most visually stunning site within the NEPTUNE observatory with its tall, smoking hydrothermal vents and light reflective pools, but it is also one of the most hostile environments on Earth (Figure 2). The Endeavour Hydrothermal Vents region is Canada's first marine protected area. All of the ONC platforms at the Endeavour site were serviced during the expedition. The Endeavour Hydrothermal Vents range in temperatures from 10 to 350°C, with high pressure conditions, black smokers, and abrupt chemical and pH changes.

HUNTING FOR WORMS 2,200 METERS DEEP

Life always finds a way, even in extreme dynamic environments. As ROV *Hercules* navigated around delicate hydrothermal vents at the main Endeavour field, the ONC team kept a keen eye out for the palm worm *Paralvinella palmiformis*, a species that is known to withstand temperatures as high as 50°C. Studying palm worms helps to map the entire genome of the species, an ongoing collaboration with researchers at the University of Montreal and Ocean University of China. A number of different species that inhabit areas around hot hydrothermal vents were sampled during the expedition, including the abundant and characteristic *Ridgeia piscesae* tubeworm (Figure 3), which has two distinct morphotypes or body forms—short-fat or long skinny.

A BONY BUFFET

Clayoquot (Tla-o-qui-aht) Slope, named after one of the fourteen nations of the Nuu-chah-nulth First Nations, is home to a whale fall that ONC has been monitoring since 2012 (Figure 4). ONC senior scientist Fabio De Leo led the ROV *Hercules* dive to map the whale skeleton using high-definition video imagery. This project constructed a three-dimensional model of the carcass through photogrammetry surveys at different points in time. Photogrammetry enables changes in the whale bones to be seen at the millimeter-scale, providing data on the degradation rates of the carcass—key to understanding the role of whale falls in supporting deep-sea ecosystems. Organisms populating this whale fall include tubeworms, gastropods, isopods, and lithodid crabs.

Figure 4. Skull and jaw bones of the whale fall documented at Clayoquot Slope.

Figure 5. High densities of the black coral *Chrysopathes speciosa* were documented during the surveys on the steepest cliffs of Barkley Canyon.

CATCHING BUBBLES AT BARKLEY CANYON

The first dive at Barkley Canyon was a quick dive to deploy the Imagenex Sonar and sonar bell to measure gas hydrates seeping from seafloor fissures. Natural gasses like methane escape from fissures in the seafloor and freeze inside cages of water molecules, becoming crystalline structures called hydrates. Conditions at this location are just right for exposed gas hydrates to be stable on the seafloor, forming large mounds of white ice—a key point of interest for deep-sea researchers, as the methane locked within these deposits is both a semi-stable and powerful greenhouse gas.

CORAL CLIFFS

Five ROV video surveys were carried out in two unexplored regions near the Western flanks of Barkley Canyon. On the steepest cliffs of the canyon, dense clusters of black corals (*Chrysopathes speciosa*) were seen to thrive, along with a number of other diverse species, such as a bubblegum coral, massive and colorful glass sponges, sea cucumbers, and a high density of rockfish (Figure 5). ONC and partner researchers are studying the effects of internal waves breaking in Barkley Canyon's steep walls that bring nutrients to support these dense seafloor communities. This study complements the ROV video observations of the coral assemblages and ONC's long time-series data. Researchers are also interested in the long-term effects of the oxygen minimum zone in the Northeast Pacific (monitored by ONC since 2009) on the physiology of these coral communities, and how they respond to ongoing ocean deoxygenation.

MAPPING CANADA'S EXPANDING MARINE PROTECTED AREAS

Using E/V *Nautilus*' sonars, the expedition mapped close to 4,000 square kilometers of seafloor, all within Canada's Exclusive Economic Zone off British Columbia. The team focused on three main regions: northwest of Endeavour to map seamounts identified by Fisheries and Oceans Canada, Cascadia Basin to plan future deployments, and Barkley Canyon areas to fill gaps in the creation of high-quality maps. Endeavour and Cascadia Basin fall within a soon-to-be designated marine protected area.

STUDYING THE ORIGINS OF THE UNIVERSE, UNDER THE SEA

Neutrino particles can only be observed by the light they emit when they collide with other particles. For the past five years, sophisticated light sensors placed on long mooring strings in the Cascadia Basin observatory site have been recording and sending their data to ONC's Oceans 3.0 data portal, demonstrating the suitability of the site to build a large neutrino telescope. The expedition recovered three neutrino sensor test moorings: two 150-meter and one 500-meter string with sensors. The recovered sensors were sent to Germany for analysis of how the physical hardware is performing in the deep ocean over extended periods of time.

Figure 6. ONC senior scientist Fabio De Leo co-hosting a ship-to-shore interaction with OET lead science communication fellow Malanai N. Kāne Kuahiwinui in the studio aboard E/V *Nautilus*.

A MATTER OF PUBLIC SAFETY

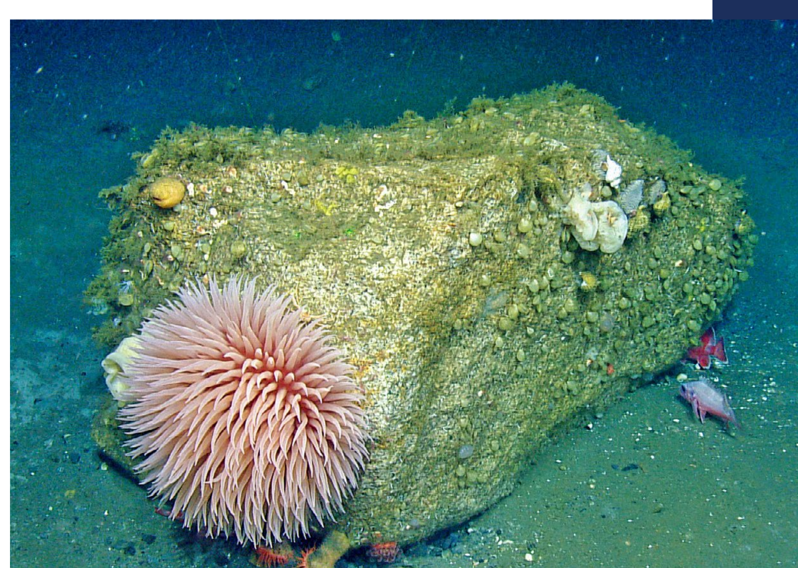
ONC's Earthquake Early Warning system includes subsea sensors located at the Clayoquot Slope, Cascadia Basin, Barkley Canyon, and Endeavour observatory sites, which were serviced and maintained during the expedition. The accelerometers are the foundational sensors of the system, as they measure an earthquake's primary (faster moving) energy wave that precedes the (slower) ground-shaking secondary wave. ONC's Earthquake Early Warning system is capable of detecting earthquakes and issuing automatic messages before major shaking arrives. This data will be shared with government organizations who issue public alerts, with messages also being sent to operators of infrastructure.

EDUCATION AND OUTREACH

ONC and OET invited ocean enthusiasts from all over the world to join this deep-sea exploration through a live streaming interactive portal that showcased expedition footage from topside cameras on deck and underwater cameras on ROV *Hercules* and *Atalanta*. During ROV dives, the audience submitted their questions through the *Nautilus*Live website, with answers provided by ONC staff or OET's science communication fellows (Figure 6). These live interactive events allowed real-time descriptions of the expedition's immediate scientific goals and its processes and technology, thus removing barriers between the public and scientists. While at sea, the expedition team created 11 new education and outreach products and hosted 32 ship-to-shore interactions with schools and community events, reaching over 1,200 people across North and South America. Early expedition results were featured in 58 media stories published in 14 countries and 12 different languages.

OPEN OCEAN DATA AND LOOKING AHEAD

In addition to data from the newly installed instruments, ROV video, and annotation data collected during this expedition were delivered to ONC for archiving and public distribution via Oceans 3.0. This advanced data management system provides high-resolution sensor measurements, video, underwater sound recordings, and data products that are used by researchers, communities, and decision-makers around the world. The 2023 expedition was funded by the Canada Foundation for Innovation and the Government of Canada. ONC and OET will partner again in 2024 to conduct an expedition aboard E/V *Nautilus* in service of ONC's cabled observatory.



EXPLORATION OF DEEP SEAMOUNT GEOLOGY AND BIOLOGY WITHIN THE JOHNSTON UNIT

OF THE PACIFIC REMOTE ISLANDS MARINE NATIONAL MONUMENT

Steven Auscavitch, Robert Pockalny, Paula Rodríguez-Flores, Raissa Hogan, Nick Foresta, Jane Carrick, Bronwyn Kay, Moronke Harris, Lila Ardor Belucci, Renato Kane, and Dwight Coleman

In 2023, E/V *Nautilus* returned to the waters of the Johnston Unit of the Pacific Remote Islands Marine National Monument (PRIMNM) thanks to support provided by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute. Expedition goals focused on understanding the geological origins and biodiversity inhabiting seamounts in the region, as well as acquiring data to support decision making relating to the Monument Management Plan that is currently being developed, and the proposed designation of the area as a new National Marine Sanctuary. ROV dive targets were concentrated on seamount features of the less explored western portion of the Johnston Unit of PRIMNM (Figure 1). A total of 11 ROV dives were conducted, each on a different seamount, which yielded 170 hours of dive time, as well as a total of 284 biological, geological, and water samples. A total linear distance of over 32 kilometers was surveyed during the ROV dives, which explored seafloor at depths between the 975–3,163 meters. Seafloor mapping efforts, critical to ROV dive planning, yielded high-resolution maps for 32,259 square kilometers of seafloor, including 19,488 square kilometers within the US Exclusive Economic Zone.

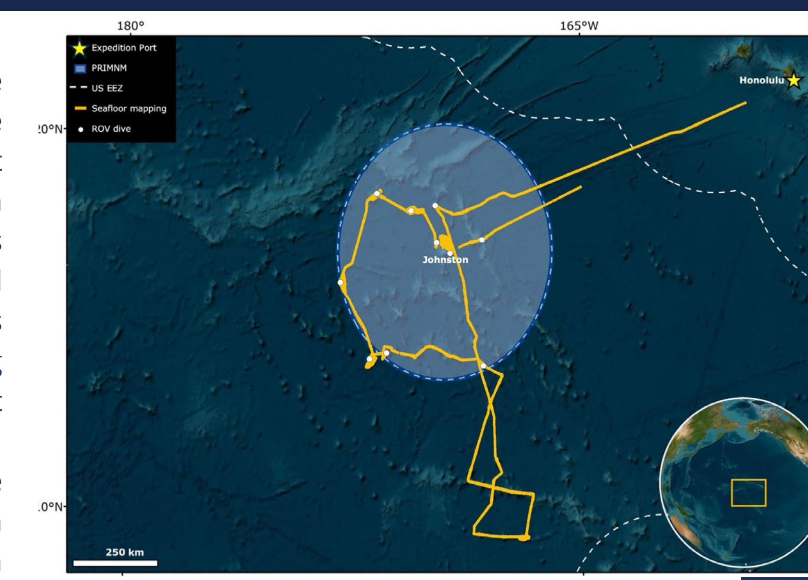


Figure 1. Map showing the locations of seafloor mapping operations and ROV dives conducted during the NA153 expedition to Johnston Atoll.

The geologic ROV dive surveys had two general approaches, including exploring potential regions where polymetallic nodules may be found on the flanks of seamounts (e.g., along the more gently sloping saddles and flat-topped summits), or targeting the edges of possible slope failures to observe geologic cross-sections. Two general patterns of nodule occurrence included extensive

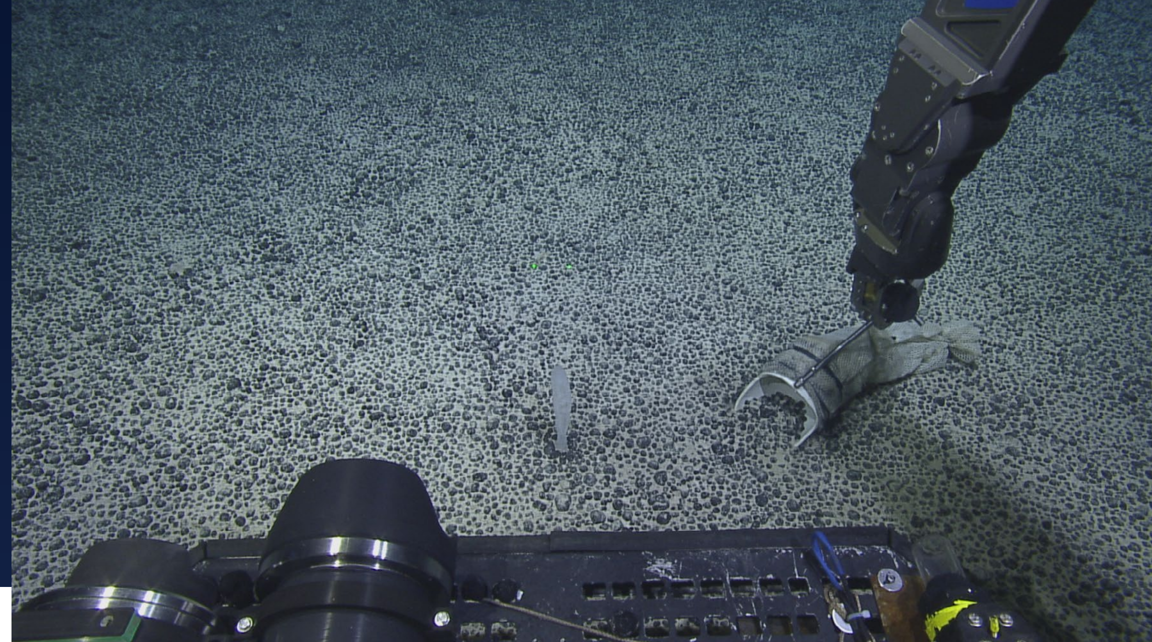


Figure 2. ROV *Hercules* scooping polymetallic "nuggets" from an expansive flat-lying region south of an unnamed seamount (H1998). Green laser dots mid-frame indicate 10 cm scale.

fields of nodules on flat sedimented regions (Figure 2), and nodules distributed along channels resembling stream beds on slightly steeper regions. Transects along the exposed scarps frequently revealed successions of lava flows with rock samples often characterized by flow breccias and hyaloclastites (Figure 3).

On those dives where the ROVs reached the seamount summit, lava morphologies were observed at or near the peak of seamounts. However, carbonate reef material may have been present just below the summit on dives H1997 and possibly H1993. Preliminary observations indicate the majority of rocks collected during the expedition represent a mixture of alkalic and highly silica undersaturated lithologies, consistent with previous reports from the region. The presence of basalt atop all of the seamount summits, and the occurrence of lava morphologies overlying carbonate reef material (e.g., H1997), suggests the possibility that some flat-topped seamounts in the region may have experienced multiple discrete phases of volcanism.

Follow-up work on collected rock samples will consist of petrographic analyses followed by age determinations via the ^{40}Ar/^{39}Ar incremental heating method and whole rock geochemical analyses in order to determine the geodynamic origin of these seamounts. The long ROV dive transects, coupled with relatively dense sampling (i.e., 6-10 rocks per dive), will allow for novel insights into how these ancient volcanoes were constructed, particularly whether they formed via a continuous event or multiple discrete pulses of volcanism.

This expedition also yielded substantial new insights into the marine biodiversity surrounding Johnston Atoll. Deep-sea corals and sponges were present at all sites, and included both high-density and high-diversity assemblages within 9 of the 11 dives. The densest observed coral communities were associated with near-summit depths at dive H1993, which was dominated

Figure 3. Meter-thick basalt flows at the top of slump scarp on western side of Johnston North Ridge (H1999).

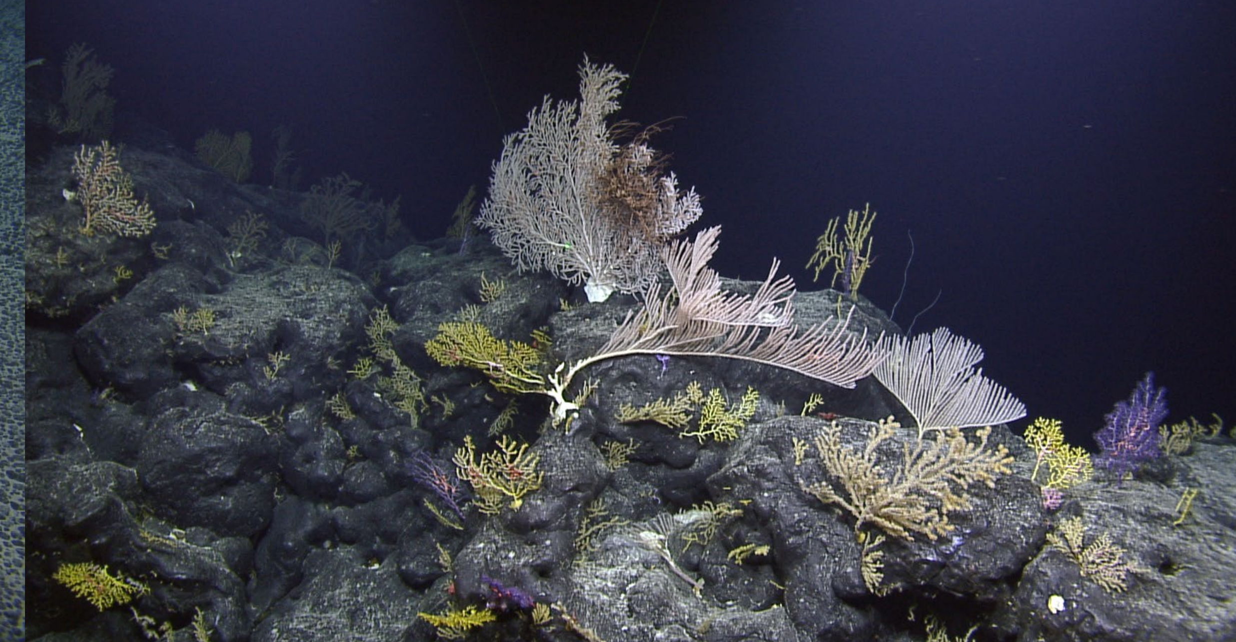


Figure 4. A dense and diverse deep-sea coral community encountered on the summit of a seamount during dive H1993.

by sea fans (including *Victorgorgia* sp.), bamboo corals, as well as an unknown *Acanthogorgia* species (Figure 4). Other noteworthy observations included a substantial woodfall (Figure 5), which included several previously unknown species records for this region. We also observed novel occurrences of seafloor gelatinous organisms, including tunicate species, which are poorly known from this region. These organisms were most commonly associated with soft sediments and small ferromanganese gravel fields, whose biological communities are not as well studied compared to high-relief ferromanganese crust communities.

This expedition also marked the beginning of a new partnership between the Ocean Exploration Trust and the Ocean Census, a global alliance that aims to accelerate the rate of new species discoveries (see Fundis and Wagner in this report). Specifically, Ocean Census affiliated scientist Raissa Hogan joined the expedition, and provided important contributions to the biodiversity expertise onboard the mission.

Johnston is the most remote atoll on Earth, and its deep-sea biodiversity is still poorly known. Biological sample collections on this mission documented several range expansions, as well as new species to science. For example, of the 24 squat lobsters (*Galatheoidea* and *Chirostyloidea*) collected on the expedition, at least nine represent new species and five include new geographic records for the Johnston Atoll region. Additionally, the six invertebrate species collected from the woodfall community were not previously known from PRIMNM (Figure 5). Among the dominant structure-forming, deep-sea corals collected throughout this expedition, at least 12 were found to be potentially undescribed species or new records for the region. This high rate of new discoveries indicates that we are only scratching the surface of understanding the true biodiversity of this remote area in the Pacific.

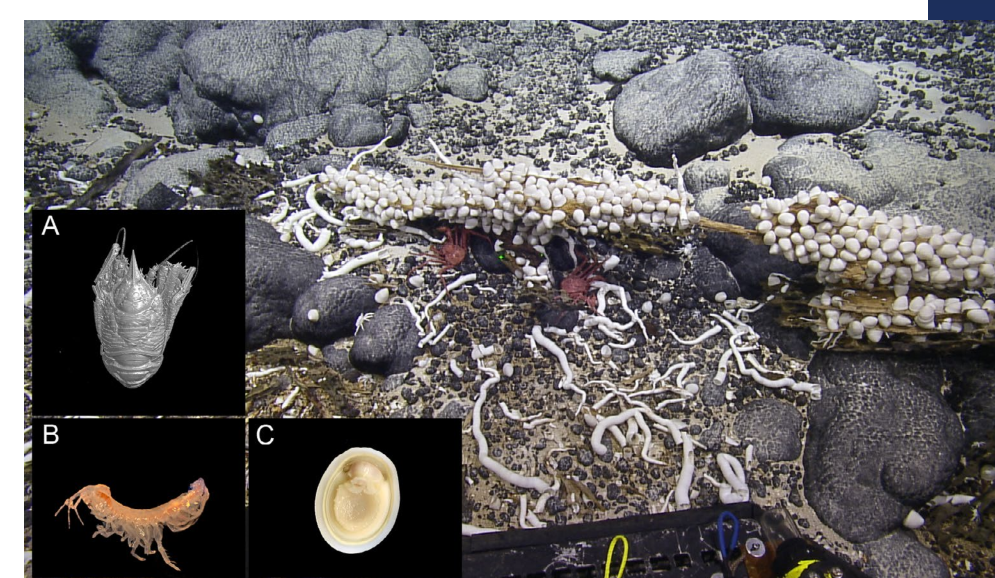


Figure 5. A woodfall community observed at 2379 meters along the northern ridge of Johnston Atoll during dive H1999. Inset images show characteristic species of the woodfall site including A) *Munidopsis* sp. squat lobsters, B) amphipod crustaceans, and C) limpet molluscs (photo credits: Paula Rodríguez-Flores).

ALA ʻAUMOANA KAI ULI:

EXPLORATION OF THE REMOTE NORTHWESTERN REGION OF THE PAPAHĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT

Valerie A. Finlayson, Michael L. Brennan, Taylorann Smith, Lily Kukui Gavagan, Virginia Biede, Sebastian Martinez, Upasana Ganguly, Hannah Paradis, Elsei Tellei, Malia Evans, Mahinalani Cavalieri, Megan Cook, and Daniel Wagner

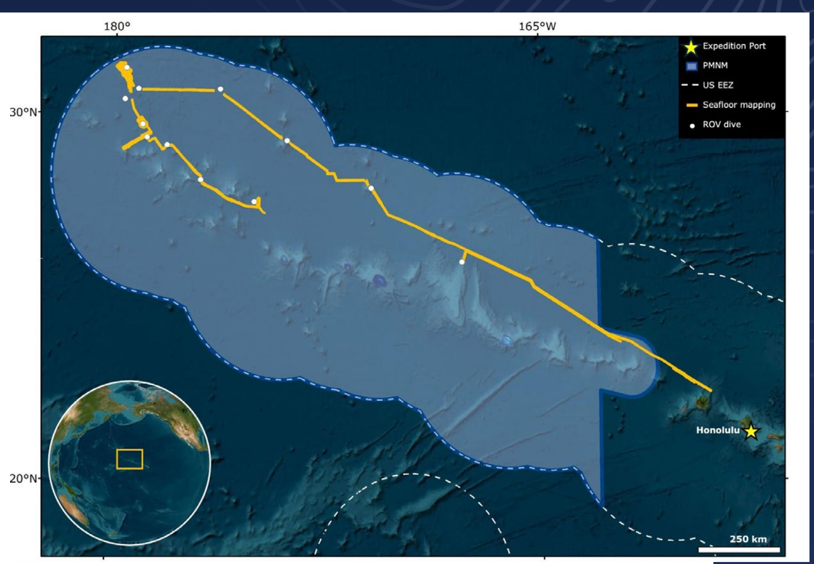


Figure 1. Map showing the locations of seafloor mapping operations and ROV dives conducted during the Ala ʻAumoana Kai Uli expedition to the Papahānaumokuākea Marine National Monument.

EXPEDITION SUMMARY

On September 1–28, 2023, E/V *Nautilus* sailed to the northwesternmost and least explored portion of the Papahānaumokuākea Marine National Monument (PMNM) with funding from NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute. Expedition objectives were to explore poorly known deep-sea environments using E/V *Nautilus*' remotely operated vehicles (ROVs) and mapping sonars (Figure 1), as well as to address science priorities of the Monument, including those identified in the Monument Management Plan, and the proposed designation of the area as a National Marine Sanctuary. This included incorporating Hawaiian worldview, cultural protocols, and Hawaiian language into expedition activities, work that was conducted in close collaboration with the Hawaiian Cultural Working Group facilitated by the Office of Hawaiian Affairs (see Morishige et al., in this report). Prior to sailing, the expedition was gifted the name Ala ʻAumoana Kai Uli (path of the deep sea traveler), a name composed in collaboration with the Hawaiian Cultural Working Group, former Kānaka ʻŌiwi (Native Hawaiian) interns, and OET.

Twelve ROV dives were conducted over the course of this 28-day expedition, three focused on archaeology, and nine focused on the geology and biology of seamounts. The expedition produced several notable scientific achievements, including detailed archaeological documentation of three aircraft carriers sunk during the Battle of Midway, surveys of six previously undocumented seamounts, and documentation of several unique biological settings. Preliminary expedition results were featured in over 1,500 news stories published in 76 countries for a combined press reach of over 7 billion.

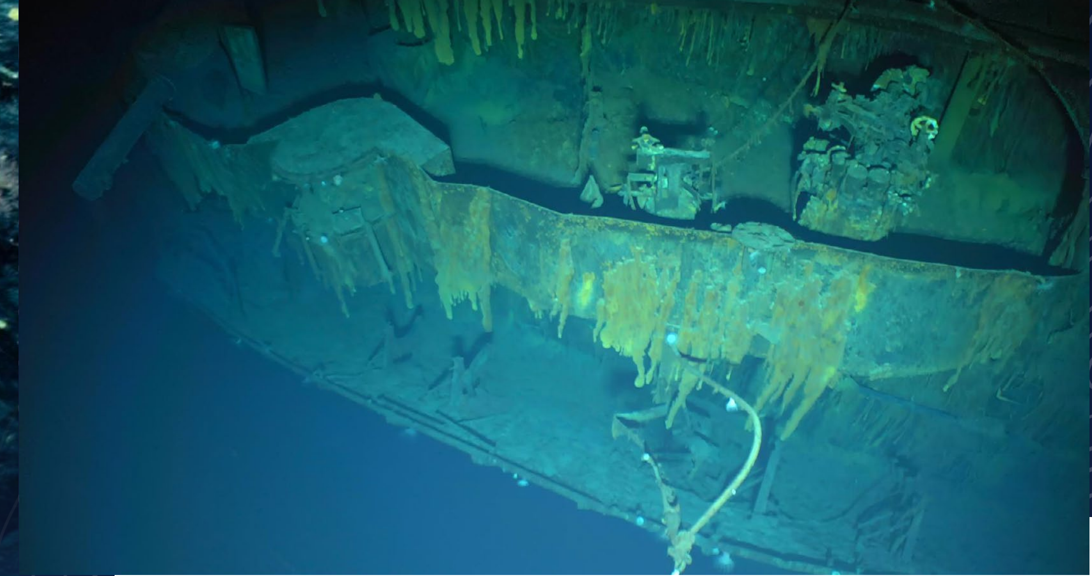


Figure 2. Guntub on the wreck of the Imperial Japanese Navy ship *Akagi* covered by rusticles, a rust formation produced by deep-water bacteria that oxidize iron and steel.

ARCHAEOLOGY HIGHLIGHTS

Ideal weather conditions permitted three ROV dives on historically-significant aircraft carrier wrecks from the Battle of Midway, USS *Yorktown*, *Akagi* 赤城, and *Kaga* 加賀 (see Brennan et al., in this report). Using a single ROV configuration with towsled *Atalanta*, the team executed three successful ROV dives to depths exceeding 5,000 meters, each of which exceeded the previous record for the deepest dive from E/V *Nautilus*. The wrecks were carefully circumnavigated to document deck and hull conditions, battle damage, and identify key features. All three wrecks were embedded in deep pelagic sediments and covered in rusticles (Figure 2). The identity of each wreck was confirmed by diagnostic features, including in the case of *Akagi*, filming the name of the ship. These dives documented numerous previously unknown details that will lend additional insight into the sequence of events that led to their sinking during the historic Battle of Midway.

BIOLOGY HIGHLIGHTS

Most of the ROV dives that did not target shipwrecks focused on volcanic ridges and fault scarps along seamount flanks at depths between 800–2,500 meters. In some cases, seamount summits and flat guyot tops were explored in order to document species more commonly found in sedimented or carbonate-capped environments, which have been largely undersurveyed. The first dive of the expedition (H2002), revealed a spectacular, vast pink *Hemicorrallium* coral forest on King George Seamount (Figure 3). On an unnamed seamount near the northwestern border of the Monument, the ROVs documented a very biodiverse and dense community (dive H2004). Several rare or undescribed species were also observed during the expedition, including a Casper octopus (dive H2010), an unknown animal informally referred to as a sea avocado (dive H2009), and a rare deep-sea pleurobranch (dive H2002). Several species, including a deep scleractinian coral and a type of red sea pen, were observed out of their known geographic ranges. The team also observed seven dumbo octopuses on various dives, with footage of one swimming that was featured in numerous media stories around the world.

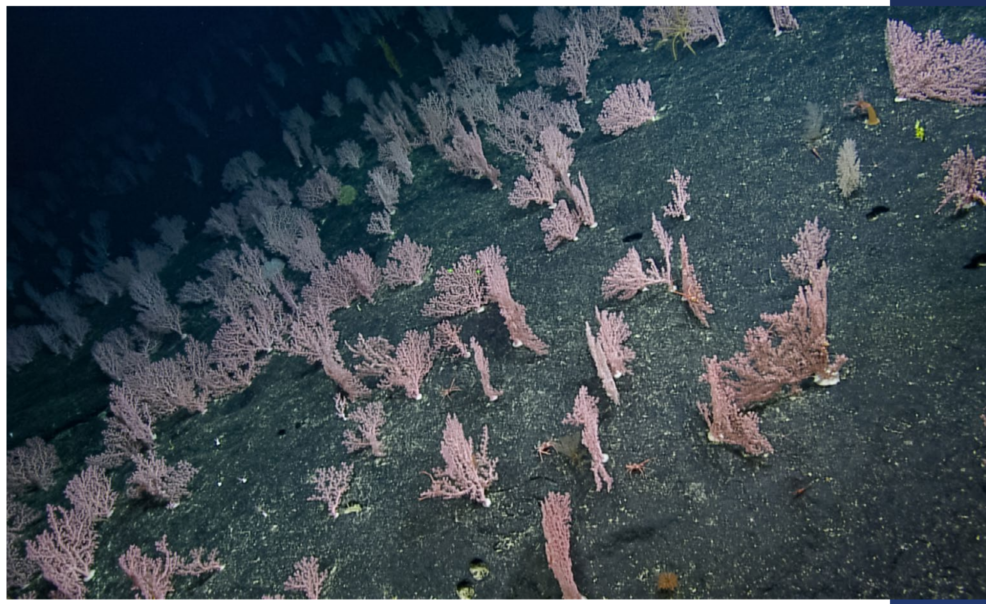


Figure 3. The ROVs documented an extensive forest of the pink coral *Hemicorallium* on King George Seamount at a depth of 1,000 meters.

Figure 4. Abundant life traces were recorded in the heavily sedimented crater of an unnamed seamount on dive H2009.

On dive H2009 on an unnamed seamount southwest of Holoikauaua (Pearl and Hermes Atoll), the ROVs summited the seamount and then entered its 1-kilometer wide crater. The crater floor was heavily sedimented and hosted several species of sea pens, halosaurids and tripodfish, along with the shrimp *Ceratapsis monstrosus*. Abundant life traces or *lebensspurren* were seen throughout the crater sediment bed, including small circular mounds several tens of centimeters across and of unknown origin (Figure 4). Much larger *lebensspurren* up to several meters long were also observed. These were tentatively identified as marks left by whales feeding on organisms burrowed into the sediments. This microhabitat had not previously been documented inside PMNM, and highlights how much more remains to be discovered in this remote region.

GEOLOGY HIGHLIGHTS

In the northwestern quadrant of PMNM, the Northwest Hawaiian Ridge intersects the Lili'uokalani Seamounts. Near this intersection lie several small seamounts of unknown age and origin. While many of the large seamounts of the Northwest Hawaiian Ridge have been documented in some manner, little work has been done on the Lili'uokalani Seamounts. Seamounts comprising the Lili'uokalani Chain are thought to be as much as ~60 million years older than adjacent seamounts, and may be related to the unusually dense hotspot activity within the present-day South Pacific Superswell.

The Ala 'Aumoana Kai Uli expedition sampled several seamounts to better understand the geological structure, age, and volcanic history of formations within the region, particularly to differentiate Cretaceous seamounts from younger ones that formed over the Hawaiian Hotspot. A total of 44 rocks were collected from eight different seamounts (Figure 5), and one on a submerged ridge north of Pūhāhonu (Gardner Pinnacles). Most of the geological samples were encrusted with ferromanganese rinds typically 1–20 millimeters thick, with rare examples up to ~60 millimeters thick, indicating at least some of the recovered samples are likely Cretaceous in age. The majority of the recovered samples represent types of basalt (aphyric, olivine-normative, clinopyroxene-normative, and ankaramitic), with a smaller sampling of hyaloclastites and sedimentary rocks, including several likely of a chemosedimentary origin. The recovered material is the process of being analyzed for geochronological and geochemical characterization. Once complete, this will provide important information to help test hypotheses about the longevity and nature of Pacific hotspot volcanism that have remained a matter of debate for decades.

Figure 5. Cross-section of a basalt rock sample collected on an unnamed seamount during the Ala 'Aumoana Kai Uli expedition.

ARCHAEOLOGY OF THE BATTLE OF MIDWAY:

EXPLORATION OF DEEP-WATER WRECKS OF *AKAGI*, *KAGA*, AND USS *YORKTOWN*

Michael L. Brennan, James P. Delgado, Hans K. Van Tilburg, Phil Hartmeyer, Alexis Catsambis, Frank Thompson, Russ Matthews, Megan Lickliter-Mundon, Jeffrey Morris, Randall Sasaki, Jun Kimura, Akifumi Iwabuchi, Aurora C. Elmore, Valerie Finlayson, Malia K. Evans, Mahinalani Cavalieri, Megan Cook, and Daniel Wagner

The Battle of Midway is recognized as one of the most consequential events of World War II that not only changed the course of the war, but also that of naval warfare. This four-day battle in June 1942 was fought across thousands of square miles north of Kuaihelani (Midway Atoll), where squadrons of American and Japanese aircraft attacked opposing aircraft carriers. Across this vast ocean stretch, the remains of the battle now lie in darkness, imprinted on the seabed over 5,000 meters below the surface. They serve as a silent witness to the ferocity of the battle, and the heroism of sailors and aviators who fought valiantly on both sides.

Multiple expeditions have searched for the five aircraft carriers sunk during the Battle of Midway. In 1998, the wreck of USS *Yorktown* (CV-5) was discovered on a National Geographic Society expedition led by Robert D. Ballard. In 1999, David Jourdan, a team from the Nauticos Corporation and the US Navy located diagnostic wreckage from *Kaga* 加賀, but not the main hull. In 2019, Robert Kraft, Paul Allen, and the Vulcan Inc. team located the wrecks of *Kaga* and *Akagi* 赤城 on an expedition aboard R/V *Petrel*. These previous expeditions, however, had limited time to visually document the carriers due to weather and equipment challenges, highlighting the extreme difficulty of accessing such remote and deep areas. The two carriers *Hiryū* 飛龍 and *Sōryū* 蒼龍, the heavy cruiser *Mikuma* 三隈, the destroyer USS *Hammann*, and hundreds of drowned aircraft remain to be found.

In September 2023, E/V *Nautilus* returned to the area, now protected under the Papahānaumokuākea Marine National Monument, as part of the Ala 'Aumoana Kai Uli expedition (NA154). Funded by NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, the expedition only had a few operational days in the area. The goal was to use this time efficiently to conduct more comprehensive archaeological surveys than had been done in the

Figure 1. The bow of *Akagi* with its wooden chrysanthemum crest identifying her as a Imperial Japanese Warship photographed by ROV *Atalanta*.

Figure 2. The stern of *Akagi* showing three painted white squares, which were presumably painted to cover the ship's name.

past, while also honoring the service and sacrifice made by Japanese and American servicemen, illustrating the importance of protecting cultural heritage, and bringing together a multi-disciplinary group of experts to comprehensively study these sites, thereby demonstrating the value of interinstitutional and international collaboration.

In an unfortunate parallel with previous expeditions, the primary ROV planned for these surveys, *Little Hercules*, suffered a mechanical issue. The team had to quickly pivot to using ROV *Atalanta* by itself, instead of the dual ROV system that is typically used on E/V *Nautilus* explorations. Nevertheless, the weather cooperated allowing for detailed ROV-based archaeological assessments of three historically-significant aircraft carriers, including the first *in situ* documentation of *Akagi*, the first detailed views of USS *Yorktown* 25 years after it was discovered, and a complete survey of *Kaga*.

The ROV descended to *Akagi* and came on site amidships on the starboard side. The iconic stack of the carrier, which was angled downward from below the flight deck, was missing, and we directed the ROV forward toward the bow. There, the gold-painted wooden chrysanthemum crest remained preserved due to the extreme depth below which wood-boring mollusks live (Figure 1). Moving along the port side, the remains of the island and bridge were apparent, although heavily damaged. Bomb damage to the flight deck was also visible. At the stern, the whited-out three-character name of the ship in *Hiragana* was also observed (Figure 2). Extensive damage notwithstanding, intact sections of the flight deck retained the telltale evidence of hits by aerial bombs dropped by American pilots. The survey also documented an open hatch near the stern, which historians interpret as proof that some crew members may have sacrificed their lives in an effort to free the rudder that had jammed due to a bomb explosion just outboard the ship.

The wreck of *Kaga* was less intact than *Akagi*, having been struck by at least five bombs, which ignited ammunition and aviation fuel in a series of massive explosions. The hangar decks and flight deck were entirely missing down to the original battleship hull of the carrier. Some of the 8-inch casemate guns, which were part of the ship-to-ship armament of the vessel's original design before it was converted into an aircraft carrier, were found remaining in place along the sides of the hull (Figure 3). A large section of upper deck was found on the seabed north of the wreck. Other displaced sections likely lie some distance away where the attack occurred. The location of the site is consistent with the vessel's reported drift before it was scuttled by Japanese destroyers. One of these torpedo strikes was visible at the mudline along the starboard side of the wreck (Figure 4). The bow was partially buried in sediment, preventing a visual inspection of its chrysanthemum crest.

Figure 3. The sides of the *Kaga* wreck contain 8-inch casemate guns, which were part of the ship-to-ship armament of the vessel's original battleship design before it was converted into an aircraft carrier.

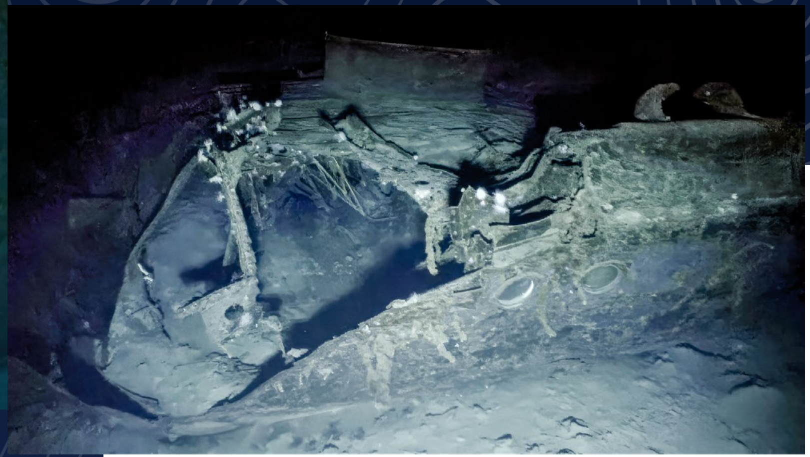


Figure 4. Starboard side of the broken stern of the *Kaga* showing a large portion where the deck and hull is missing.

The wreck of USS *Yorktown* lies nearly 300 kilometers east of *Kaga* and *Akagi*, illustrating the breadth of the battlefield; at no time were any of the American and Japanese carriers in sight of one another. ROV *Atalanta* first saw the carrier's stack and island, which showed evidence of fire damage caused by the bomb that struck the flight deck near the tower. The bow indicates the wreck's starboard list as it settled into the seabed (Figure 5), which had also been observed during the 1998 survey. The hangar doors were largely missing. Gun tubs showed evidence of where the crew had used acetylene torches to cut open the tubs to jettison the anti-aircraft guns to right the vessel as it listed (Figure 6). While no evidence of aircraft was found on the seabed, what appears to be a detached wing from one of *Yorktown*'s planes was observed inside a debris-filled hangar.

A comparison of these three aircraft carrier shipwrecks powerfully shows the differences in their sinkings. In particular, the crew of the *Yorktown* was able to extinguish fires caused by bomb damage, patch the flight deck, and even begin to right the ship before the Japanese submarine *I-168* struck *Yorktown* with two torpedoes that ultimately doomed it. In contrast, *Akagi* and particularly *Kaga*, show more extensive bomb and fire damage.

The field of maritime and naval archaeology has in recent years shifted from assessing individual sites to the study of more expansive landscapes and battlefields. The Battle of Midway is likely the world's largest naval battlefield and still needs to be mapped and explored. While the NA154 expedition documented several new aspects about this pivotal battle, the wrecks of *Sōryū*, *Hiryū*, *Mikuma*, USS *Hammann*, as well as hundreds of drowned aircraft remain to be found. The 2023 Battle of Midway exploration dives were made possible by the expertise, support, and collaboration of many partners, including Ocean Exploration Trust, *Nautilus* Corps of Exploration, NOAA Ocean Exploration, NOAA Office of Marine National Sanctuaries, US Naval History and Heritage Command, Defense POW/MIA Accounting Agency, SEARCH Inc., Teikyo University, Tokai University, Tokyo University of Marine Science and Technology, Air/Sea Heritage Foundation, International Midway Memorial Foundation, and Bureau of Ocean Energy Management.

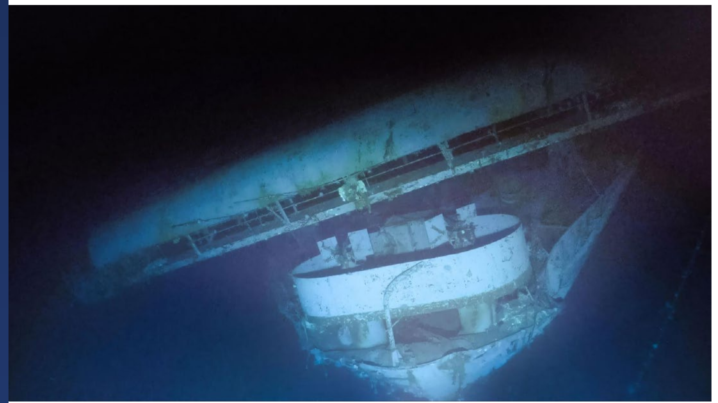


Figure 5. The bow of USS *Yorktown* showing a list to the starboard side, a feature that was also documented during the 1998 surveys led by Robert D. Balland that first located the wreck.

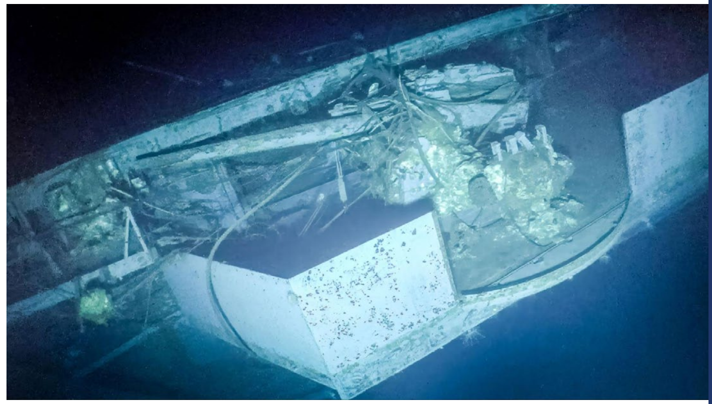
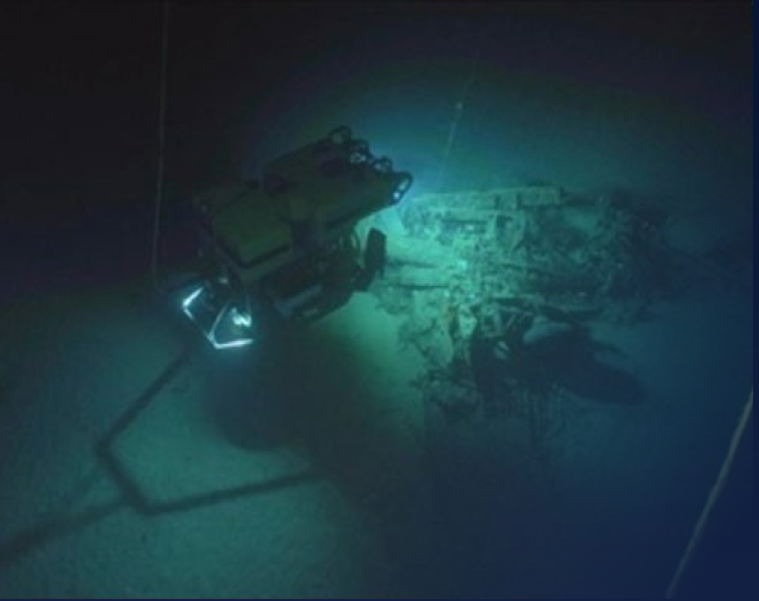


Figure 6. Large cut-outs on the side of USS *Yorktown* made by its crew in an attempt to jettison the anti-aircraft guns and right the vessel as it listed.



COLLABORATIVE ARCHAEOLOGICAL SURVEY OF A WWII HAVOC A-20 BOMBER OFF HAWAI'I

Hans K. Van Tilburg, Daniel Wagner, and Alba Mazza

During the 2023 ROV shakedown expedition (NA148), E/V *Nautilus* executed a two-day mission supported by a new Ocean Exploration Trust (OET) partner, the Defense POW/MIA Accounting Agency (DPAA), a division of the US Department of Defense charged with providing the fullest possible accounting of military personnel lost while performing their duty. Technical assistance for the mission was provided by the NOAA Maritime Heritage Program, an initiative of the Office of National Marine Sanctuaries. The purpose of the mission was to conduct a non-invasive archaeological survey of an aircraft wreck located offshore O'ahu in order to characterize the crash site, and if possible, identify its lost crew.

On September 29, 1941, a Douglas A-20 Havoc medium bomber departed the Hickam Army Airfield on a routine training mission with two crew members onboard. Early into the flight, the aircraft suffered an engine failure and fell out of formation, losing altitude rapidly, and impacting the ocean offshore. Observers reported that the aircraft's forward compartment tore up into thousands of pieces when hitting the water. A crash boat was dispatched, but no survivors were recovered.

A portion of the wreck was discovered in 2011 during surveys by the Hawai'i Undersea Research Laboratory (HURL) using their manned submersible *Pisces V*. HURL provided images and position data from those surveys, which were used to plan the 2023 mission. On May 10, 2023, E/V *Nautilus* conducted a seafloor mapping survey over the site using its Kongsberg EM302 multibeam sonar and Knudson 3260 sub-bottom profiler. Backscatter data revealed several targets that were consistent in size, shape, and position with the site reported by HURL. These targets were then used to plan an ROV groundtruthing survey using ROV *Hercules* and towsled *Atalanta*, which was conducted on May 11, 2023.

Figure 1. Mosaic of the main wreckage of the A-20 Havoc bomber, which consists of the inverted right wing with landing gear (top), tail empennage (left), and cockpit (lower right).

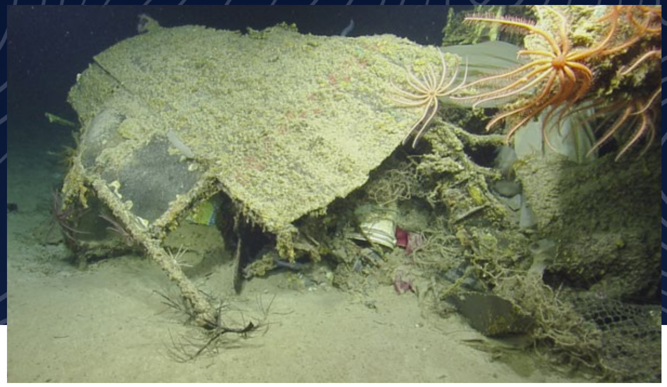


Figure 2. Right side of the cockpit with pilot seat and armored headrest visible, along with debris and possible parachute on the right side.

The objectives of the ROV survey were to (1) locate and confirm the aircraft type, (2) determine site extent, condition, and major features, and (3) examine the cockpit and other features that may contain human remains. The main wreck was located early in the ROV dive and debris trails were investigated around it. Ultimately, all major features consistent with a twin-engine military bomber were identified, with exception of portions of the left wing, one propeller, and the nose compartment, which was reported to be destroyed during the crash.

The survey confirmed the preliminary identification of the aircraft as an A-20 Havoc lost in 1941 by diagnostic features, specific data on manufacturer's plates, and correspondence between wreckage and eyewitness reports of the crash. The aircraft settled in one main location, surrounded by various aircraft pieces scattered nearby. The main wreckage is composed of the right side of the cockpit, inverted right wing and engine nacelle with main landing gear, lower fuselage area and structural elements of the gunner's position, and entire tail assembly with fin, rudder and tailplanes (Figure 1). No human remains were observed. The sole piece of life support equipment is what appears to be a parachute, apparently deployed from its bag by ocean currents over time (Figure 2). Outward of the main wreck site, several other airplane parts were located, including the nose landing gear (Figure 3), left engine and wing portion (Figure 4), right engine, propeller, and other debris.

All data and images from the surveys have been transmitted to DPAA, along with a detailed report summarizing the findings of the mission. In addition to implementing a new partnership, this brief two-day mission also helped refine techniques that were used during archaeology surveys conducted later in the 2023 E/V *Nautilus* season, including those of aircraft carriers off Midway (see Brennan et al., in this report), and Japanese submarines off O'ahu (see Fahy et al., in this report). Collaboration and partnerships are critical to exploring our largely unknown ocean. OET's mission of ocean exploration and technological innovation merged very well with DPAA's mission to bring closure to military families, and also supported NOAA efforts to inventory maritime heritage resources. With shared purpose and teamwork, a lot can be accomplished in a short amount of time.

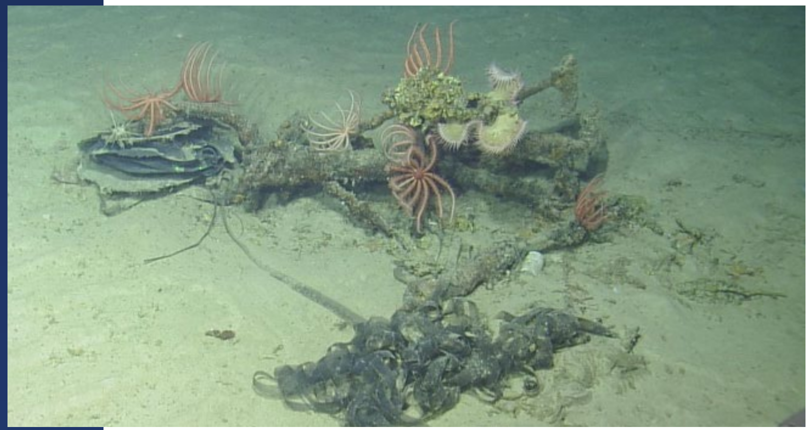


Figure 3. Support strut and delaminated wheel of the Havoc nose landing gear, which was located 63 meters away from the main wreckage.

Figure 4. Inverted left wing portion, engine nacelle, and heavily deteriorated radial engine, which was located 79 meters away from the main wreckage.

OCEAN EXPLORATION THROUGH ADVANCED IMAGING

Jason Fahy, Jonathan Fiely, Robert D. Ballard, and Larry Mayer

The Ocean Exploration Trust (OET) has a long history of innovation with advances in deep submergence technologies, telepresence, and mapping tools. In 2022, OET was funded by the Office of Naval Research to develop a new generation of deep-sea imaging systems designed to collect immersive imagery for use in virtual and augmented reality. The Ocean Exploration through Advanced Imaging expedition (NA156) was a dedicated effort to test this new Widefield Camera Array (see Fiely et al., in this report), which brought with it new onboard workflows. The expedition also utilized the Norbit wideband multibeam sonar mounted on ROV *Hercules*.

In order to push the limits of these technologies, we selected sites around the Main Hawaiian Islands covering a wide range of depths, topographies, and habitat types (Figure 1). These sites had all been previously explored using manned submersibles operated by the Hawaiʻi Undersea Research Laboratory and recommended by their pilots due to their complex topography and stunning scenery. Over the course of this 14-day expedition, the team successfully integrated the new Widefield Camera Array onto ROV *Hercules* (Figure 2), and used it to survey a wide diversity of complex terrain, including steep ridges, pinnacles, submarine canyons, hydrothermal vents, and large submarine wrecks.

Figure 1. Map showing the locations of ROV dives conducted during the NA156 expedition.

The expedition completed 14 successful ROV dives for a total dive time of over 101 hours and over 76 hours exploring the seafloor at depths between 375–1,865 meters. During the ROV surveys, the team developed new protocols that increased the efficiency of seafloor surveys. Specifically, multibeam data collected by the Norbit wideband multibeam sonar during the ROV approach to the seafloor was used to develop detailed seafloor maps, and then precisely move the ROV towards areas of interest without wasting time searching for targets.

Figure 2. The new Widefield Camera Array installed on ROV *Hercules*. The system consists of three modular cameras, two that are mounted side by side in the center of the vehicle and a third that is mounted on the upper bumper bar centered amongst the LED lights.

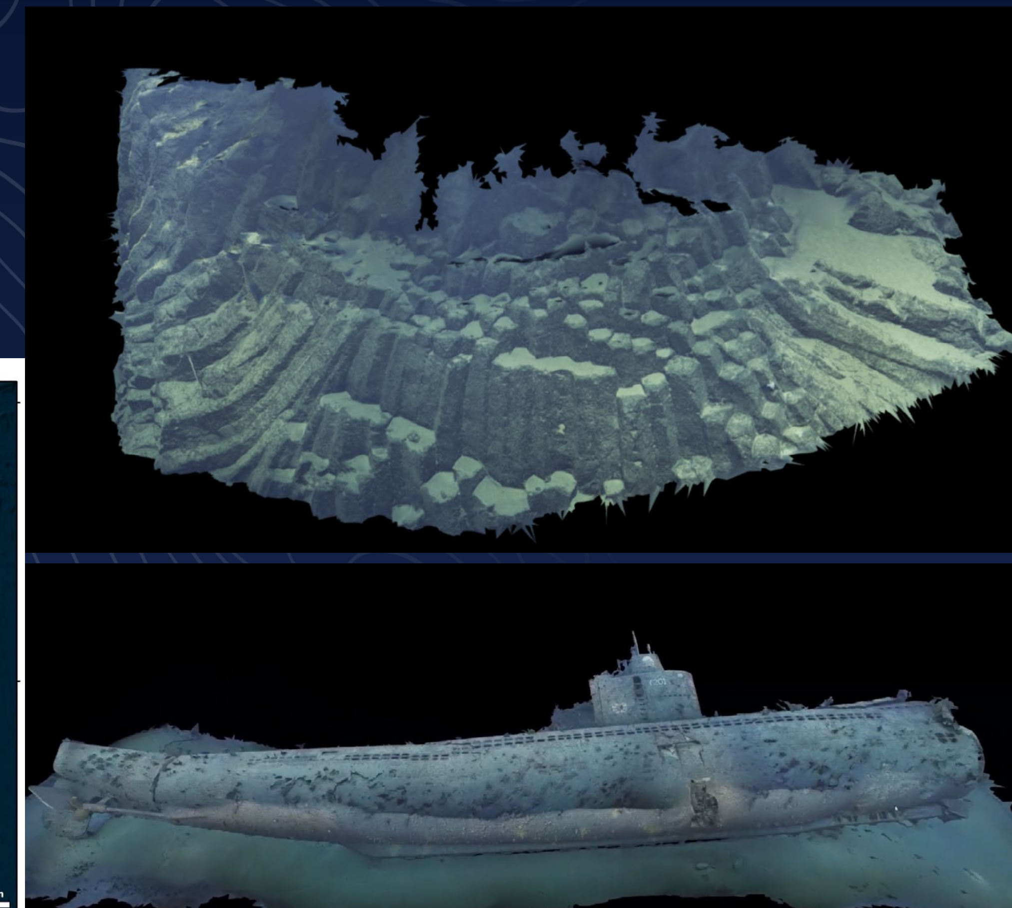


Figure 3. Using Reality Capture software, the NA156 onboard team quickly developed photorealistic models of the sites being explored by the ROV, such as of this columnar basalt formation off Molokaʻi (top) and the Japanese submarine I-201 off Oʻahu (bottom).

The expedition also resulted in a new way for OET to share exploration data. The team onboard E/V *Nautilus* created digital models of the site being explored by the ROVs (Figure 3). These photorealistic models were developed shortly after data was collected, often while the ROVs were still exploring the site. These near real-time models allowed the team to virtually explore the sites as if they were themselves diving on the site. Applications of this new exploration paradigm are still being developed, but these digital models did provide some very valuable contextual information and situational awareness that allowed the onboard team to visualize features that may have otherwise been missed.

To create these models the team collected thousands of ultra-high-resolution images that were stitched together using Reality Capture, the modeling software behind many popular video games. In concert with new workflows to develop these models, the team also tested avenues for sharing models with the public, including via Sketchfab and Cesium Ion, the latter of which included georeferenced versions of the models. In addition to providing avenues for public distribution, these platforms reduced the need to share large video files with shore-based project collaborators, thereby providing important savings in bandwidth.

An additional innovation put into practice during this expedition was a unique visualization of multibeam data collected by the ROV-mounted Norbit wideband multibeam sonar. Mapping the seafloor using ROVs is not new, but the virtual representation of the ROV in the real-time map was unique and provided another type of immersive experience which ultimately provided new insights. In post processing data from the multibeam was also used to verify and where necessary calibrate the digital models. This multilayered approach to producing accurate seafloor models is powerful and will be an area of research for OET in the coming years.

OET is proud to have taken our latest innovations into some of the most complex underwater terrain in the Central Pacific, and successfully integrated them into at sea operations. Besides advancing new technologies for ocean exploration, the NA156 expedition also supported other Office of Naval Research priorities by welcoming educators and students onboard as members of the *Nautilus* Corps of Exploration. Three Science Communication Fellows, three Science and Engineering Interns, and three additional students participated in the expedition, gaining valuable at-sea experience.

COLLABORATIVE MAPPING AND CHARACTERIZATION OFFSHORE OF THE HAWAIIAN ISLANDS

Mark Mueller, Cheryl Morrison, Derek Sowers, and Chris Roman

The Hawai'i Mapping Expedition (NA157; November 7–17, 2023) was a hybrid mapping and water column characterization expedition meant to collect fundamental baseline information about biological, geologic, and oceanographic attributes in relatively poorly surveyed areas offshore of the main Hawaiian Islands. Collecting seafloor mapping data, including bathymetric data on the depth and shape of the seafloor and backscatter data for insights on seafloor composition, improves geological understanding and supports the development of benthic habitat classification and suitability maps. This information helps scientists and managers alike better understand the relative ecological importance of different deep-sea environments.

This expedition set some exciting new precedents for the Ocean Exploration Trust and its partners. In addition to frequent partner NOAA Ocean Exploration, the Bureau of Ocean Energy Management co-funded this expedition and provided six interdisciplinary subject matter expert scientists onboard the E/V *Nautilus*, including a co-lead scientist and an avian biologist. Three scientists from the US Geological Survey also sailed, contributing important expertise in eDNA sampling

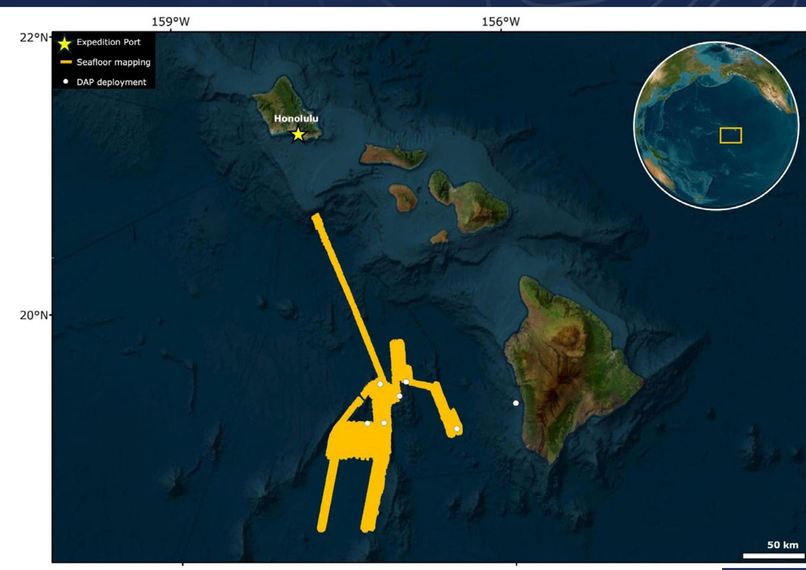


Figure 1. Map showing the locations of seafloor mapping operations and Deep Autonomous Profiler deployments conducted during the NA157 expedition.

Above. Close-up photo of a Wedgetailed Shearwater *Ardenna pacifica* (photo credit: Dave Pereksta).

and seafloor mapping classification. These federal scientists worked seamlessly with the rest of the *Nautilus* Corps of Exploration to meet multiple shared regional and national science objectives, including addressing all five goals of the US National Strategy for Ocean Mapping, Exploration and Characterization.

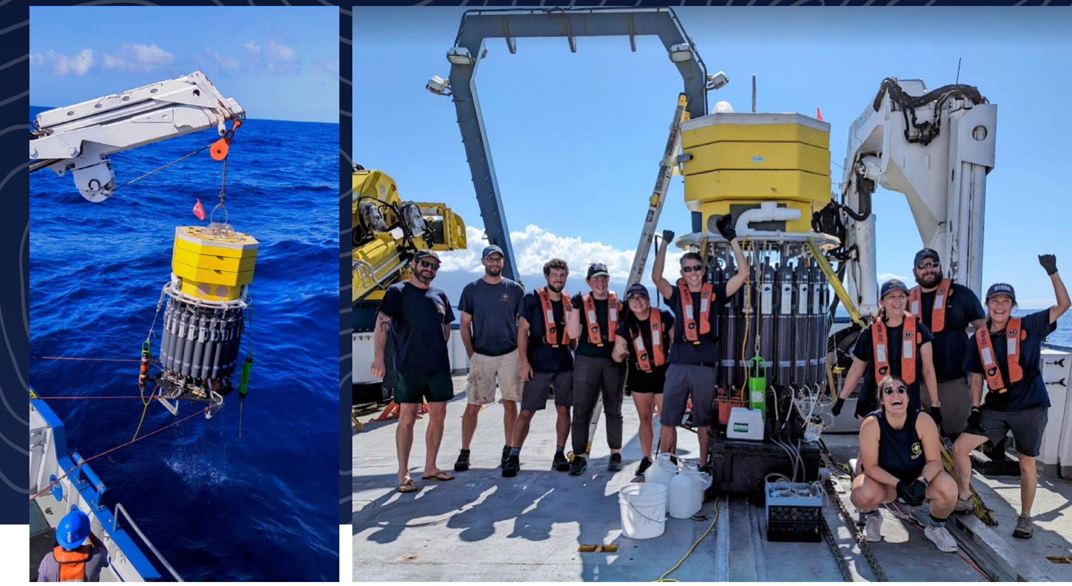
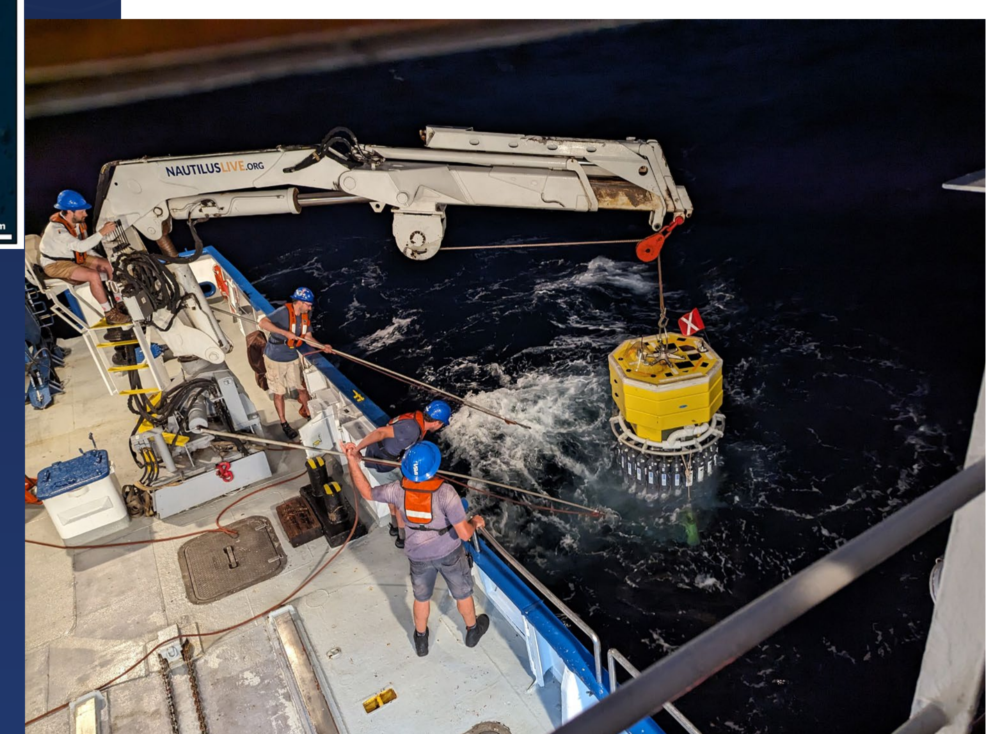


Figure 2. The Deep Autonomous Profiler (DAP being deployed during the NA157 Expedition (left). Part of the NA157 expedition team after the final successful water sample collection (right).

One such priority was filling seafloor mapping gaps throughout southern portions of the US Exclusive Economic Zone near Hawai'i. The original geographic priority area for the expedition was nicknamed the Crescent due to its shape. However, due to consistently severe weather in that area throughout the expedition (30 knot winds and 11-foot seas), E/V *Nautilus* operations were instead limited to the relatively sheltered lee of the island of Hawai'i. Fortunately, in consultation with multiple shoreside scientists including the US Geological Survey and the University of Hawai'i at Mānoa, several contingency areas of research and management interest were quickly identified. These areas were largely in abyssal basins (3,000–5,000 meter depths) with poor backscatter coverage surrounding the Geologist Seamounts, with a focus on areas near Perret, Cook, Jaggar, and Indianapolis Seamounts. A total area of 5,911 square kilometers was mapped in these areas using the E/V *Nautilus*' EM302 multibeam sonar (Figure 1). Additionally, the subsequent E/V *Nautilus* mapping expedition to Jarvis Island (NA158), was able to complete three days of focused mapping in the original Crescent area.



Characterization of aspects of the water column was another expedition goal. In addition to mapping, 166 water samples were collected throughout the water column and at the seafloor using the University of Rhode Island's Deep Autonomous Profiler (DAP) (Figure 2). The DAP is an uncrewed platform capable of deploying a suite of oceanographic sensors and cameras along with 24 Niskin bottles down to 11 kilometers depth (see Roman and Casagrande in this report). It operates untethered, allowing the ship to deploy the vehicle and temporarily leave the area to conduct other work before returning later for its retrieval. Over the course of seven successful

Figure 3. Bureau of Ocean Energy Management Avian Biologist Dave Pereksta (left) conducting seabird surveys with help from student ocean explorer Jose Cisneros (photo credit: Mark Mueller, BOEM).

deployments, the DAP collected water samples at planned depths with the purpose of later analyzing those samples for particulate organic matter, nutrients, and environmental DNA (eDNA). Analysis of eDNA is a novel method that uses trace amounts of genetic material shed by all forms of organisms to help identify and characterize biodiversity. Led by the US Geological Survey, the retrieved water samples were filtered on deck using peristaltic pumps and encapsulated eDNA filters, which were preserved for later processing on shore. DNA indicate species presence at these remote locations, potential food sources, and environmental conditions, providing important information to guide management decisions.

In another E/V *Nautilus* first, an avian biologist conducted topside visual surveys of seabird diversity and abundance (Figure 3). Over 76 survey hours, 946 individual birds from 22 species were documented and recorded in standardized databases for the region. In an unexpected use of eDNA for this mission, an opportunistic sample (from bird feces) was preserved from what could potentially turn out to be a species of storm petrel that has never before been documented in this area. If confirmed by US Geological Survey scientists, this would represent a significant change in biological understanding of this species.

As with all OET expeditions, education and community outreach was a key part of this expedition, which sailed with three student interns as part of the Science & Engineering Internship Program. Working alongside the variety of federal scientists aboard provided some extraordinary training and mentorship opportunities for these interns. Finally, Science Communication Fellow Beverly Owens put the Art in STEAM education with her Mappin' & Dappin' graphic (Figure 4), and unique Motion of the Ocean acrylic paint pours artwork (Figure 5).

Figure 4. Artwork, expedition motto, and collectible sticker created by Science Communication Fellow Beverly Owens during the NA157 expedition.

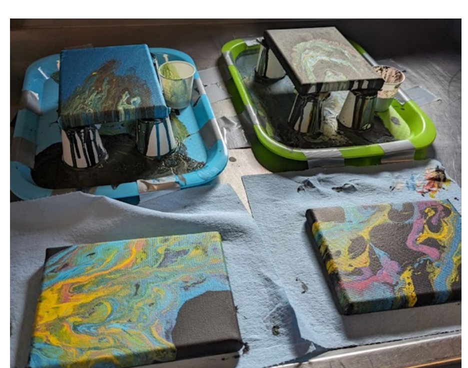
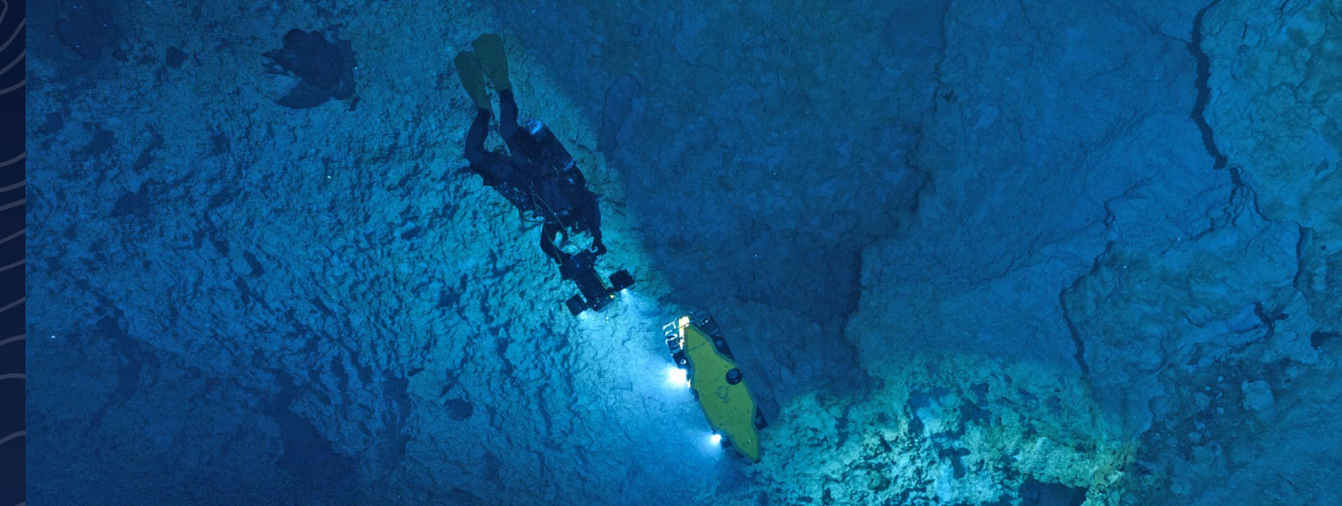


Figure 5. "Motion of the Ocean" artwork developed by Science Communication Fellow Beverly Owens during the NA157 expedition (photo credit: Mark Mueller, BOEM).



WAKULLA SPRINGS EXPEDITION:
OVERVIEW OF TECHNOLOGIES AND RESULTS

Jason Fahy, Jonathan Fiely, Robert D. Ballard, and Larry Mayer

INTRODUCTION

Funded by the Office of Naval Research, the Wakulla Springs Expedition took place from February 1–15, 2023 at Edward Ball Wakulla Springs State Park, approximately 20 miles south of Tallahassee, Florida. A collaborative effort between Stone Aerospace, Karst Underwater Research, and Ocean Exploration Trust, the expedition's primary objective was to explore complex underwater terrain using a new ultra-high resolution camera mounted on the Autonomous Underwater Vehicle (AUV) *SUNFISH*.

This expedition was in stark contrast to OET's expeditions aboard E/V *Nautilus*, as Wakulla Springs is landlocked, shallow, and filled with freshwater, leaving us to explore a much different environment. These differences pushed us to bring in new expertise and technologies to explore one of America's most unique environments. Key partner Stone Aerospace provided AUV *SUNFISH*, which has the unique ability to maneuver with six degrees of freedom. In a confined space like the submerged Wakulla cave system, a robot that can pivot and spin to negotiate tight quarters is a must. Being highly maneuverable with the ability to hold station, made AUV *SUNFISH* an ideal imagery platform for this project. OET integrated a new cinema-grade camera onto the AUV, which added ultra-high resolution imagery to the multibeam sonar data collected by the vehicle. Having the ability to collect images at precise intervals allowed the team to use cutting-edge software coming out of the video game industry to develop the first digital models of the spring's interior, allowing virtual exploration of the cave without the inherent hazards of technical SCUBA diving.

EXPEDITION TEAM AND RESOURCES

To explore the cave, we assembled a team of 14 onsite personnel, who supported AUV operations, as well as executed technical SCUBA dives in support of AUV surveys (Figure 1). The AUV conducted 14 dives, while technical SCUBA divers undertook 28 dives. The technical SCUBA divers were critical to the mission, as they allowed the team to focus on adapting the acoustic navigation systems of the AUV to the complex cave environment, without having to worry about losing the vehicle. With the confidence that technical SCUBA divers could rescue the AUV if needed, the team was able to aggressively test new navigation algorithms for the vehicle.

Figure 1 (above). The shore-based Wakulla Springs expedition used AUV *SUNFISH* and technical SCUBA divers to image the complex underwater cave system at the Edward Ball Wakulla Springs State Park (photo credit: Michael Barnette).

Figure 3. High-resolution image of a portion of the Sally Ward Spring commonly known as the cube room. A simulated model of AUV *SUNFISH* was added for scale.

TECHNOLOGICAL INNOVATIONS

The team successfully implemented three technological innovations during the mission. First, the AUV was equipped with a state-of-the-art 6K camera capable of capturing ultra-high-resolution imagery (Figure 2). Second, advances in the AUV's acoustic navigation technologies, coupled with its six degrees of freedom maneuverability, allowed the team to move through the complex terrain. AUV *SUNFISH* successfully navigated using advanced acoustic imaging and Doppler Velocity Log systems, albeit with some issues due to the demanding environment. Third, the team used 360 imagery to create photorealistic comprehensive models of the caves.

ACHIEVEMENTS

The mission marked a historic moment as it was the first to autonomously explore the Wakulla Springs, a feat not previously achieved due to the complexity and risks associated with such a complex environment. Utilizing the collected imagery, the team successfully generated detailed models of the underwater terrain (Figure 3). These models were created overnight from an extensive collection of over 28,000 images.

Over 3.8 terabytes of data were collected during the expedition, demonstrating the scale of the operation and the capabilities of the equipment. Another notable achievement was the creation of the first interior cave model of Sally Ward Spring, highlighting the expedition's ability to explore, map, and model previously unexplored underwater structures.

COMMUNITY AND SCIENTIFIC IMPACT

The expedition received enthusiastic support from the Florida Department of Environmental Protection. The Wakulla Springs State Park hosted two public outreach events over the course of the mission, during which hundreds of people engaged with the expedition team. Building on that success, the State Park is also in the process of preparing an exhibit at their onsite museum that will highlight the achievements of the expedition.

The Wakulla Springs Expedition stands as a pioneering example of how innovative technology can be leveraged to explore complex underwater environments. The successful deployment of an AUV equipped with advanced imaging technologies in a very challenging underwater environment, as well as the creation of detailed underwater models, all contribute to the expedition's legacy. The high-resolution models developed for the underwater cave system not only provide invaluable tools for scientific research, but are also powerful tools for education, outreach and conservation of these hard to access and delicate ecosystems.

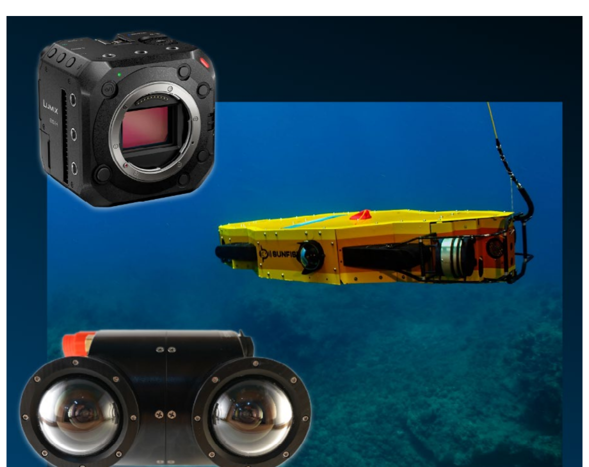


Figure 2. The mission focused on the integration of immersive imaging technologies onto AUV *SUNFISH*, including a Panasonic BSH1 cinema-grade camera (top left) and Arctic Ray Machine Vision camera (bottom left).

COLLABORATIVE OCEAN EXPLORATION:

EXAMPLES OF NEW OET PARTNERSHIPS IN 2023

Allison Fundis and Daniel Wagner

At OET, our goal is to explore the vast and poorly known parts of our ocean using cutting-edge technologies and share our findings with a global audience. We believe partnerships are essential to achieving this mission, given its magnitude. We are proud to have worked with many long-standing OET partners that are detailed throughout this report —including NOAA Ocean Exploration and NOAA Ocean Exploration Cooperative Institute (Soule et al.), Office of Naval Research (Ballard et al., Fahy et al.), Ocean Networks Canada (Paulson et al.), Inner Space Center (Coleman et al.), Museum of Comparative Zoology (Baldinger et al.), Marine Geological Samples Laboratory (Kelley et al.), and Papahānaumokuākea Marine National Monument (Morishigue et al.)—as well as new collaborators that joined us in our 2023 field season.

One of our new partnerships was with the Defense POW/MIA Accounting Agency (DPAA), a division of the US Department of Defense dedicated to accounting for military personnel lost in the line of duty. Through this partnership, we successfully executed a two-day mission to survey a US Air Force plane wreck that occurred in 1941 (Figure 1). Technical assistance for the mission was provided by the NOAA Maritime Heritage Program, as well as the Hawai'i Undersea Research Laboratory, the

Figure 1. During the 2023 ROV shakedown expedition (NA148), E/V *Nautilus* executed a mission for the Defense POW/MIA Accounting Agency (DPAA) with technical assistance by the NOAA Maritime Heritage Program.

Figure 2. The 2023 Hawai'i Mapping expedition (NA157) was an interagency collaboration that included onboard participation from the Bureau of Ocean Energy Management, US Geological Survey, and NOAA Ocean Exploration along OET mission personnel.

latter of which first located the aircraft wreck back in 2011. This mission highlighted how much can be accomplished in a short amount of time when we all work together towards a common goal (see Van Tilburg et al., in this report).

In November 2023, we were pleased to have the Bureau of Ocean Energy Management (BOEM) co-sponsor an expedition with us alongside our long-standing partner, NOAA Ocean Exploration. This ten-day E/V *Nautilus* expedition included the participation of six interdisciplinary scientists from BOEM, as well as three scientists from the US Geological Survey and one from NOAA Ocean Exploration. Together, we worked towards advancing inter-agency science priorities (Figure 2), including those of the US National Strategy for Ocean Mapping, Exploration, and Characterization (see Mueller et al., in this report).

In addition to these partnerships, we also welcomed several more new partners onboard E/V *Nautilus* during the 2023 season. One of the highlights was our collaboration with the Science, Technology, Engineering, And Math Student Experiences Aboard Ships (STEMSEAS) program, a National Science Foundation-supported program that provides at-sea experiences for undergraduate students from diverse backgrounds (Figure 3). This new partnership brought aboard nine undergraduate students who were able to experience for the first time the life of at-sea exploration and utilize E/V *Nautilus* as a mobile classroom. Mentored by three experienced STEMSEAS educators, who also sailed on the ten-day expedition from Hawai'i to British Columbia (NA150), students gained valuable exposure to at-sea field research, as well as were able to network with OET mission personnel and learn about the varied pathways leading to careers in ocean exploration and research.

Another new exciting partnership for us was with Ocean Census, a collaborative project between the Nippon Foundation, Nekton, and a consortium of alliance partners that aims to greatly accelerate the discovery of marine life, catalyze its conservation, and build the human capacity needed to support

Figure 3. Nine undergraduate students and three educators from the STEMSEAS Program sailed on the 2023 transit mapping expedition from Hawai'i to British Columbia (NA150).

Figure 4. Ocean Census-affiliated scientist Raissa Hogan sailed on the ROV expedition to Johnston Atoll (NA153), during which she provided valuable taxonomic expertise.

this large-scale effort. OET officially joined the existing network of Ocean Census Alliance partners in 2023, as well as welcomed Ocean Census-affiliated scientist Raissa Hogan on the ROV expedition to Johnston Atoll (NA153), who provided important taxonomic expertise throughout the expedition (Figure 4). We were also joined remotely by Ocean Census Science Director Alex Rogers and Ocean Census Science Manager Denise Swanborn, who provided their expertise as scientists ashore.

In September, we were privileged to welcome Palau International Coral Reef Center researcher Elsei Tellei onboard our Ala 'Aumoana Kai Uli expedition to the Papahānaumokuākea Marine National Monument (NA154). In addition to seeing how the operational capabilities of E/V *Nautilus* were used to survey the unique natural and cultural resources of a large marine conservation area, Tellei provided unique insights on how these capabilities could be implemented to explore deep ocean habitats around Palau, where E/V *Nautilus* will operate in October–November 2024. Following Tellei's participation on the NA154 expedition, the Palau International Coral Reef Center hosted OET staff in a series of meetings with stakeholders in Palau to help plan the 2024 expeditions to the region (Figure 5).

Our collaborative approach to ocean exploration has enabled us to advance our mission of exploring the largest ecosystem on our planet, the deep sea, and sharing it with a global audience alongside our partners. We are grateful to all of our partners, only some of which have been mentioned here. Our partners are essential to helping us meaningfully connect our collective work with audiences across the globe, especially with individuals and communities in the regions in which we explore, so that our expeditions are implemented in inclusive and ethical ways.

Figure 5. In October 2024, the Palau International Coral Reef Center hosted OET staff members for a series of stakeholder meetings to start planning E/V *Nautilus* expeditions to Palau in 2024 (photo credit: Hiromi Ito).

ADVANCING NOAA'S OCEAN EXPLORATION COOPERATIVE INSTITUTE (OECI)

Adam Soule and Aurora C. Elmore

The Ocean Exploration Cooperative Institute (OECI) brings together five world-class research organizations to support NOAA Ocean Explorations's mission. Together, University of Rhode Island, Woods Hole Oceanographic Institution, University of New Hampshire, University of Southern Mississippi, and Ocean Exploration Trust work hand-in-hand with NOAA Ocean Exploration to accelerate the pace of ocean exploration, advance ocean exploration technologies, increase the utility of ocean exploration data, and train the next generation of ocean explorers with an emphasis on increasing diversity. Currently in its fifth year, OECI has been approved to seek renewal for another five years of operation through 2029.

The OECI represents an integrated ocean exploration enterprise that has the expertise to shepherd new technologies from conception to development to application. This is accomplished by leveraging the strengths of its five affiliate institutions, as well as in partnership with more than 40 other academic institutions and industrial partners, in addition to the close collaboration and support from NOAA Ocean Exploration. While OECI efforts directly benefit NOAA Ocean Exploration, they have also proven valuable to a range of additional federal partners, including NOAA Fisheries, NOAA Office of Coast Survey, Bureau of Ocean Energy Management, and the US Geological Survey.

Ocean Exploration Trust's E/V *Nautilus* provides the expeditionary platform for many OECI activities (Figure 1). In 2023, OECI-funded expeditions aboard E/V *Nautilus* mapped over 100,000 km^2 of seafloor in the US Exclusive Economic Zone of the Pacific Island Region, completed 65 successful ROV dives, as well as launched 54 deployments of other uncrewed vehicles, landers, and profilers. Adding to those 2023 accomplishments, many of the technology development projects that were supported in the initial years of the OECI, are now being applied to a range of ocean exploration activities. Among them, the University of New Hampshire uncrewed surface vessel *DriX* successfully integrated a deep-water sonar. Through a tremendous collaboration between the University of New Hampshire, Exail and Kongsberg, both *DriX* and a standard deep-water sonar were redesigned, enabling *DriX* to map seafloor at depths over 3,000 meters (see Mayer et al., in this report).

Figure 1. E/V *Nautilus* provides a critical platform to deploy various emerging technologies from partner institutions of the OECI.

Collaborative explorations conducted between *DriX* and Woods Hole Oceanographic Institution's autonomous underwater vehicle *Mesobot* resulted in the development of new approaches to midwater exploration (see Hayden et al., and Govindarajan et al., in this report). By combining the sensing capabilities of *DriX* with the sampling capabilities of *Mesobot*, directed verified sampling of midwater scattering layers was accomplished for the first time. Further, the eDNA sampling system developed for *Mesobot* has recently been ported to other vehicles, expanding our ability to explore marine ecosystems from the surface to the seafloor. The *Mola Mola* and *Eagle Ray* autonomous underwater vehicles from the University of Southern Mississippi conducted their first operations from NOAA Ship *Okeanos Explorer*, adding a new ability for high-precision seafloor mapping and characterization at depths up to 2,500 meters.

OECI has been fortunate to share the experience of ocean exploration and technology development across many stakeholder communities. This includes the public that is invited to follow along live with our at-sea exploration activities through telepresence, as well as students participating in OECI research via University of Southern Mississippi's Ocean Explorers Internship Program, University of Rhode Island's Bridge to Ocean Exploration Program, and OET's Science and Engineering Program.

INSPIRING GLOBAL AUDIENCES VIA OCEAN EXPLORATION AND EDUCATION

Jamie Zaccaria, Megan Cook, Kelly Guarino, Jonathan Fiely, and Jacob Ottaviani

From breaking newsworthy explorations of shipwrecks to inspiring a myriad learning moments throughout the year, our global audiences were offered a front-row seat to explore fascinating deep-sea environments via our website, newsletter, and social media, as well as the many press outlets that featured our work. Breaking records for the number of ship-to-shore interactions, highlight videos, social media followers, and press reach, 2023 was a banner year for sharing ocean exploration with the world.

As part of OET's commitment to transforming the ocean exploration community to more equitably include and amplify historically-marginalized voices, OET's education and outreach team was active in bringing down barriers and providing hands-on training to the next generation of explorers. As E/V *Nautilus* explored the Pacific, we continued to work closely with partners to ensure our expedition storytelling appropriately reflected local culture and was guided by Indigenous knowledge. In all programs, OET emphasized the importance of workforce role modeling and highlighted every person sailing on E/V *Nautilus* as a role model regardless of age, profession, or background. Through our website and digital media outreach efforts, we celebrated the significant impact diverse role models can have on anyone following our expeditions from around the world.

Figure 1. E/V *Nautilus* is a teaching and learning platform where mentoring connects all teams through hands-on experiences like STEMSEAS student Skyy Sumlin learning to gather water column data with Mapping Coordinator Renato Kane.

HANDS-ON LEARNING AT-SEA

2023 saw the most diverse cohort of educators and students in OET's history joining our at-sea programs, with 80% of the 23 interns and 16 educators self-identifying from backgrounds historically underrepresented in STEAM. OET's Science and Engineering Internship Program provides at-sea opportunities to deepen students' understanding of ocean science and engineering by fostering teamwork, developing skills, and applying their knowledge to real-world problems. The program trains early career professionals studying ocean science, seafloor mapping, underwater vehicle engineering, and video systems through paid at-sea internship positions, during which they are embedded in the expedition team.

The Science Communication Fellowship program invites formal and informal educators to sail onboard E/V *Nautilus* as expedition storytellers and work together to bring ocean exploration to their communities. In 2023, the fellowship cohort taught in a wide variety of settings, from public schools to outdoor education and afterschool programs to scientific illustration on social media. This year, six fellows were from islands in the Pacific, including our first participants from Guam and American Samoa, thereby helping connect our work to the geographies where E/V *Nautilus* will be operating in coming years.

Throughout the year, fellows were active in building excitement and imparting the significance of STEAM career pathways and ocean exploration to students and communities, with over 60% of fellows working directly with Title-1 eligible schools and historically marginalized community groups.

"In my community, most people look like me, but we are not well represented in the world of STEAM. As I visit local schools, I am hopeful that it will inspire more to get involved in science and exploration."

– 2023 Science Communication Fellow

Through partnerships, including NOAA Ocean Exploration Cooperative Institute's Ocean Explorer Internship Program and the NOAA Educational Partnership Program, OET expanded the number of at-sea opportunities for learners, particularly those from historically-marginalized backgrounds. Additionally, this year, OET partnered with the National Science Foundation STEMSEAS program to bring a dozen students and educators onto E/V *Nautilus* (Figure 1). STEMSEAS provides exploratory experiences for undergraduate students from diverse backgrounds to engage in geoscience and oceanography activities.

REACHING MILLIONS THROUGH LIVE STREAMS AND SOCIAL MEDIA

The *Nautilus* Live website provides many ways for public audiences to engage with ocean exploration, including our 24-hour live stream that brings footage from our expeditions to screens around the world in real time. Across the eight-month expedition season, our live streams attracted over 1.41 million views, with an average watch time of over fourteen minutes—an extremely high metric for educational content and an increase over previous seasons. Additionally, the team received and answered over 30,000 questions from audiences watching live.

Nautilus Live Community Growth on Social in 2023

- 175K (+43K or 33%)
- 111K (+1K or 1%)
- 44K (+2.5K or 6%)
- 3K (+2K or 64%)
- 517K (+51K or 10%)
- 11.2K (+495K or 4,415%)

NAUTILUS LIVE
OCEAN EXPLORATION TRUST

Figure 2. Social media continues to be a growing force in connecting with global audiences; 2023 saw growth across all OET social media channels.

In 2023, our team produced a new record of 101 highlight and education videos, which attracted over 9.38 million views. Popular videos connected viewers with historical archaeology, unique deep-sea creatures, and the teams and technology behind our expeditions. We also produced several new animated educational videos, including an Ocean Literacy Principles series that explains common ocean phenomena.

Social media coverage across six popular platforms elevated expedition discoveries, at-sea stories, and *Nautilus* Corps of Exploration role models (Figure 2). OET's social media channels now have more than 1.4 million followers, with the most active engagement on YouTube and TikTok, both with extensive youth participation. On Instagram, we hosted 40 story takeovers, allowing explorers to share their unique perspectives, including features of the ship's crew and our word of the day series in ʻŌlelo Hawaiʻi (Hawaiian language) and American Sign Language (Figure 3).

CONNECTING TO CLASSROOMS AND COMMUNITIES

OET's live ship-to-shore interactions connect role models with onshore audiences in K-12 classrooms, universities, museums, science centers, and out-of-school programs (Figure 4). These connections allow audiences around the world to learn about ocean exploration directly from the at-sea team and ask questions to those aboard. Expanding our 2023 impact, explorers hosted 710 ship-to-shore interactions in English, ʻŌlelo Hawaiʻi, American Sign Language, Spanish, Samoan, and Palauan. Altogether, we reached about 30,500 learners in 44 US states, 4 US territories, and 19 countries.

"This was such a great experience for students! I love that they connected with a world so far removed from their own and that they could see themselves in some of the onboard roles. Introducing students to a wide variety of career options is one of our school goals and this experience went a long way towards that goal."

— Live interaction participant

Figure 3. Science Communication Fellows bring their unique talents and passions to E/V *Nautilus*, such as Christopher Clauss explaining ocean exploration concepts in American Sign Language.

Figure 4. The unique broadcast studio setup of E/V *Nautilus* allows ocean explorers like educators Katie Doyle and Anneliese Haleck to chat with students live making personal connections with onboard personnel.

OET also supported the development of a wide variety of educational materials, including Next Generation Science Standard-aligned STEAM Learning Modules available in Spanish, ʻŌlelo Hawaiʻi, and English, as well as podcasts, teaching animations, and creative challenges, all freely available via the *Nautilus* Live and Deep Ocean Education Project websites. In 2023, OET published 14 new resources to enhance our ocean exploration educational content, including lessons rooted in Hawaiian pedagogy and language, technical three-dimensional printing activities, and the continuation of the Storytime at Sea series with children's books read by explorers paired with lessons.

Nautilus Live Media Summary 2023

3,867 articles total with 1,943 about 2023 expedition season

- **1,560: Ironton in Lake Huron**
- **797: Battle of Midway**
- **698: dumbo octopus**
- **106: octopus garden publication**
- **96: Education & Outreach**
- **77: mysterious orange jellyfish**
- **57: Japanese submarines 3D imaging**

NAUTILUS LIVE
OCEAN EXPLORATION TRUST

Figure 5. Thanks to extensive coverage of our expeditions in national and international media outlets, OET efforts in 2023 reached billions of people worldwide.

HIGHLIGHTING OUR EFFORTS AND PARTNERSHIPS

Bringing ocean exploration to billions, OET's work was highlighted in 3,867 media articles in 2023 (Figure 5). Eight decades after the WWII Battle of Midway, our exploration stories aimed to honor the service and sacrifice forever part of this historic battleground. Content from our Battle of Midway explorations were featured in 797 media pieces for a combined press reach of 7.1 billion. Other popular media topics that captured audiences' imagination included the discovery of the sailing ship *Ironton* in Lake Huron and spectacular deep-sea creatures such as the dumbo octopus or the newly discovered *Bathykorus* jellyfish species. Elevating our explorers within their home communities, OET also worked closely with participants and local press to publish nearly 100 stories featuring students and educators that sailed on E/V *Nautilus*.

OET continues to be committed to exploring poorly known parts of our ocean and to sharing the excitement of discovery with people of all ages to inspire the next generation of ocean explorers. We look forward to continuing this critical work in 2024 and beyond. In 2023, OET's education and outreach programs were supported by the Office of Naval Research, the National Marine Sanctuary Foundation, CITGO, NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute, and the NOAA Educational Partnership Program.

CONTRIBUTIONS OF THE INNER SPACE CENTER TO E/V *NAUTILUS* OPERATIONS

Dwight Coleman, Rachel Simon, Christopher Knowlton, Derek Sutcliffe, and Deborah Smith

The Inner Space Center (ISC) at the University of Rhode Island Graduate School of Oceanography has been the shore-based hub for telepresence operations since the first season of E/V *Nautilus* in 2009. Fourteen seasons later, ISC continues to provide telepresence and data engineering technical support for E/V *Nautilus* operations with funding from NOAA Ocean Exploration via the Ocean Exploration Cooperative Institute. Throughout this 15-year partnership, ISC team members continue to improve upon previous seasons by providing technical solutions to video streaming and data processing, in addition to other more routine satellite, network, video, and data engineering tasks.

A new project for the 2023 season involved working in creative ways with the high-resolution video files that come off the ship. ISC assists OET with managing that data and making it publicly available via various avenues. During 2023, ISC Data Engineer Rachel Simon developed a computer code that streamlines the process by preparing video data for (1) upload to YouTube (2) delivery to the NOAA National Centers for Environmental Information, and (3) hosting by Amazon Web Services.

Uploading the ROV video recordings to YouTube has been important to the E/V *Nautilus* program, as it allows shore-based researchers to view dives on demand, as well as easily find video segments of interest (Figure 2). ISC uploads full ROV dive recordings to YouTube into video playlists organized by expedition. For the 2023 season, video recorded by the main high-definition camera on ROV *Hercules* was aggregated into 2-hour segments, which were paired with the relevant data log entries made during that dive. The data log entries then become chapters in the YouTube video, allowing viewers to quickly find sections of interest such as when the ROV arrived on bottom, collected a sample, or documented a noteworthy feature.

The ISC is also experimenting with supporting cloud storage operations for long-term archiving. Onboard the ship, media files are transferred to tapes using generic linear tape file system (LTFS) technology, so files can easily be hand carried to shore. The generic LTFS protocol avoids brand lock-ins, where viewers become dependent on proprietary tape formats. In past installations proprietary tape formats were unavoidable, and therefore ISC maintains a system that can read old tapes and pass commands that request data from those tapes. Fifteen years ago we used LTO4 tapes with a capacity of 800 gigabytes each. The LTO7 cartridges used today store 6TB of raw video data, and expeditions typically span several tapes. These tapes are more durable than hard drives, which is particularly important for getting large amounts of data safely through travel or shipping. The tapes are checked on shore using LTFS drives with onboard host bus adapters, making them the most portable LTFS solution available for use on Mac, Windows, or Linux.

Before being archived by the Amazon Web Services Simple Storage Service, the tapes are inspected and copied to a spinning disk. Copies can be stored in the service tier called Deep Glacier Archive for long-term, low-cost storage. The tradeoff for this long-term storage is that there is a slightly higher fee and potential long lead times to pull data out of the archive. Using Amazon Web Services, we have the ability to migrate files between different tiers, so that users can access the files directly.

Figure 1. Since 2009, data engineers at the Inner Space Center have provided critical support to live streaming and video data processing to the E/V *Nautilus* program.

Combining this work with the YouTube full dive recording workflow has led to other advances in video data management. A goal is to have all full-dive video products (i.e., full resolution and proxy versions of the video collected by both ROV *Hercules* and the towsled *Atalanta*) processed via the same system, using existing lists of dives, with minimal manual intervention. Videos are then checked, organized and prepared for delivery to the NOAA National Centers for Environmental Information.

ISC is also partnering with OET, the NOAA Ocean Exploration Cooperative Institute, the University of Southern Mississippi and the NOAA National Centers for Environmental Information to explore cloud indexing and delivery of videos in the future. Using Amazon Web Services, videos will be archived and made available via Aquaview, a program developed by the University of Southern Mississippi that will index the contents of the archive as well as generate required metadata. The index will make it easier to find video content of interest. This partnership is laying the groundwork for the future delivery of video products to public archives. One of the goals for this new project is automating video data management to provide data access in a consistent and rapid manner.

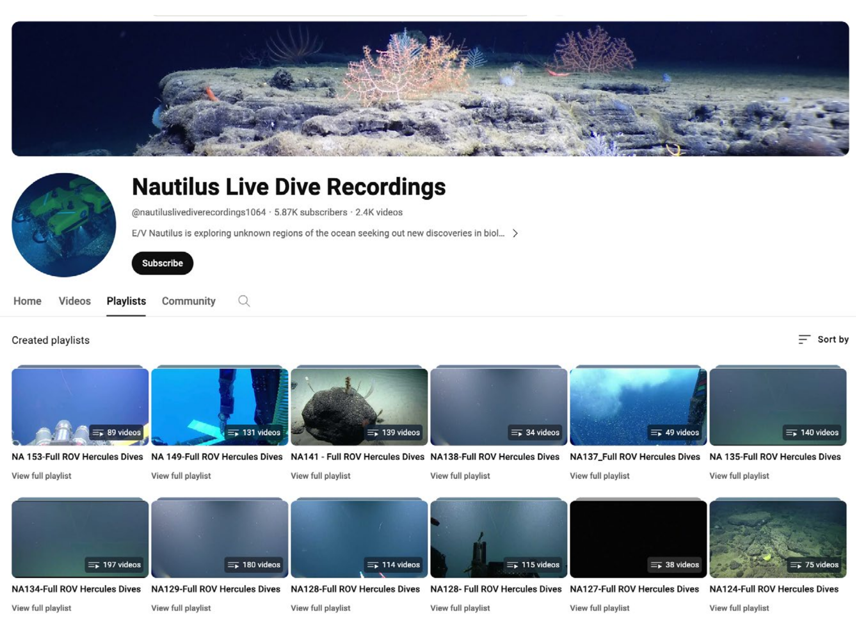


Figure 2. Full dive recordings of video collected by the high-definition camera on ROV *Hercules* are uploaded to YouTube. Videos are uploaded into 2-hour segments that are organized into playlists by expedition.

ALA ʻAUMOANA KAI ULI:

SHARED EXPLORATION OF THE DEEP OCEAN THROUGH EQUITABLE AND ETHICAL PARTNERSHIPS WITH INDIGENOUS COMMUNITIES

Kanoeʻulalani Morishige, Malia K. Evans, Megan Cook, Mahinalani Cavalieri, Hōkūokahalelani Pihana, and J. Hauʻoli Lorenzo-Elarco

Moananuiākea, the expansive ocean known today as the Pacific, is an Indigenous space of ancestral knowledge passed down through millennia and perpetuated by Indigenous communities to this day. To better understand the ocean, particularly in places like Hawaiʻi, it is critical to overcome systemic barriers that have marginalized Indigenous knowledge and peoples. This transformation requires a genuine commitment to learn from and engage with Indigenous communities, who have navigated, explored, and lived in sync with the ocean since time immemorial, and thereby developed a deep understanding and extensive knowledge.

Since 2020, OET has been working to build an equitable and ethical partnership with members of the Papahānaumokuākea Native Hawaiian Cultural Working Group and the Papahānaumokuākea Marine National Monument in order to appropriately weave Hawaiian culture into expeditions. Cultivating trust and pilina (relationships) was foundational to co-developing expeditions that equally value Indigenous knowledge systems and Western science. This meant having open and respectful conversations about systemic barriers to Indigenous participation, as well as avoiding tokenism and performative actions, as these can be harmful to Indigenous communities even when they come with good intentions. The co-production process focused heavily on Indigenous self-determination captured in the saying, "nothing about us, without us," which was reflected in strategies employed both onboard the ship and during shore-based activities.

While E/V *Nautilus* sailed through Hawaiʻi, bringing along our global community of explorers, we emphasized the importance of entering Hawaiʻi Pae ʻĀina (the Hawaiian Islands) with a mindset of openness, humility, and learning. We worked to cultivate environments where all expedition participants can weave together their knowledge, and elevated priorities determined by local Pacific Island and Indigenous communities. It is critical to emphasize that this work was only possible through building a foundation of trust, which underpinned the willingness to learn and eventually begin implementing a much-needed paradigm shift. With each expedition, the co-production process included many meetings to genuinely listen to the guidance of Indigenous partners and community members, who shared their perspectives and community priorities.

Figure 1. To date, this partnership has provided opportunities for 14 Kānaka ʻŌiwi (Native Hawaiian) educators, scientists, students, and cultural liaisons, who brought their expertise E/V *Nautilus* expeditions, including this team from the Ala ʻAumoana Kai Uli expedition (NA154).

Through this partnership multiple new programs have been developed, including (1) the creation of expedition names reflecting Hawaiian relationships with the intent of expeditions, (2) a glossary of Hawaiian language terms related to ocean science and exploration technologies, (3) development of Hawaiian language names for deep-sea species, (4) live broadcasting in ʻŌlelo Hawaiʻi (Hawaiian language), (5) development of educational resources framed through a biocultural lens and Kānaka ʻŌiwi worldview, (6) establishment of an onboard cultural advisor role dedicated to maintaining respectful relationships with sacred Indigenous spaces, and (7) dedicated at-sea opportunities for Kānaka ʻŌiwi (Native Hawaiian) students and educators.

In 2023, this partnership expanded learning opportunities to set expectations of a two-way knowledge exchange with Indigenous engagement as a high priority for all OET staff, science communication fellows, and expedition participants. These trainings shared Indigenous values, knowledge and practices, and highlighted synergies between Indigenous and Western scientific approaches. Additionally, they emphasized how to communicate about this work with public audiences across the world. This was followed by briefings for all expedition participants, which dove in deeper on the cultural significance of places to be explored.

The 2023 E/V *Nautilus* expedition to the northwestern section of Papahānaumokuākea (NA154) was of particular importance to this work, as this area is recognized as an ʻāina akua (realm of the gods) to Native Hawaiians. This expedition was gifted the name Ala ʻAumoana Kai Uli (path of the deep sea traveler), a name composed in collaboration with the Papahānaumokuākea Native Hawaiian Cultural Working Group, former Kānaka ʻŌiwi interns, and OET. The expedition name speaks to the work done on this mission, as well as the shared responsibility that we all have in protecting our

Figure 2. Cultural protocol guided our team to respectfully engage with the ʻāina akua, a sacred realm, and the biological, geological, and archaeological elements found within Papahānaumokuākea.

ocean. Ala ʻAumoana Kai Uli is a reflection of our collective experiences as people who love the ocean. This name incites images of physical and metaphoric paths, connecting us to each other and various spaces within the ocean. These paths have been meticulously tended to over time, and the name also reminds us of our shared responsibility to care for these paths and our ever-developing relationships. The Ala ʻAumoana Kai Uli expedition name also forms the ending lines to an original oli (chant) that was composed to document the relationships that the OET team are growing to better understand Papahānaumokuākea.

One of the partnership's major priorities was to increase the participation of Kānaka ʻŌiwi onboard E/V *Nautilus*. Native Hawaiian and Pacific Islanders continue to be severely underrepresented in STEM, especially in ocean science and maritime careers. Together we sought to actively build capacity for Kānaka ʻŌiwi to be leaders in connecting expeditions to local audiences in Hawaiʻi and across the Pacific. To date, this partnership has provided opportunities for fourteen Kānaka ʻŌiwi to sail on E/V *Nautilus* as interns, science communication fellows, science managers, resource monitors, and cultural liaisons (Figure 1). All of these positions were paid, to appropriately honor the important expertise that these participants contributed to each expedition. As youth see people from their communities on these expeditions, they can see themselves as scientists grounded in their identity.

The Ala ʻAumoana Kai Uli expedition to Papahānaumokuākea succeeded specifically because of the depth that these approaches were interwoven in expedition activities. Understanding this special place through its cultural significance provided opportunities for deeper storytelling and connecting with global audiences in new ways. As the mission visited never-before-seen seafloor features, the abundance and diversity of this sacred, protected place were revealed to the world. Kānaka ʻŌiwi explorers were part of every watch, and contributed significantly to the narrative of live-streamed dives through a cultural lens. When expedition highlights were picked up by the press, the Native Hawaiian intern who filmed those moments served as the feature interview.

As the team explored the final resting places of aircraft carriers sunk during the Battle of Midway (see Brennan et al., in this report), global audiences fascinated by this history were granted the unique opportunity to also see this event through a different lens. While the Battle of Midway wrecks were the result of a historically-significant event that occurred 81 years ago, this area has also been considered a sacred place for Hawaiians for over a millennium. Each ROV dive was launched and closed with protocol ceremonies to honor this sanctity, in ways that reflected their significance to Kānaka ʻŌiwi, Japanese, and U.S. communities (Figure 2).

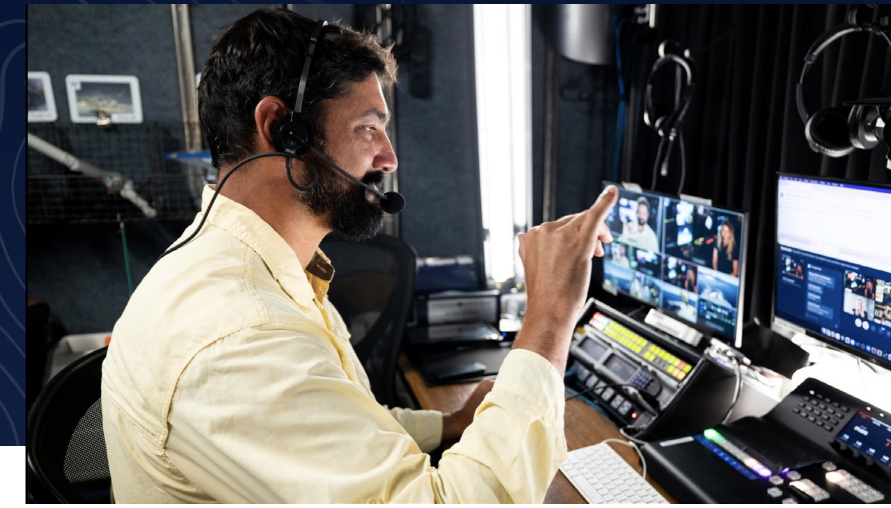


Figure 3. Ala ʻAumona Kai Uli expedition Lead Science Communication Fellow Daniel Kinzer.

This partnership seeks to strengthen relationships to the deep ocean for learners of all ages. Together we developed over a dozen new educational products grounded in Kānaka ʻŌiwi worldview. Two new educational activities and three new video products were produced exclusively in ʻōlelo Hawaiʻi. The team also worked together to develop new video products including introducing global audiences to the significance of cultural protocol, the pilina (relationships) that cultivated the growth of this partnership, and a Meet an Explorer series to elevate Kānaka ʻŌiwi role models. Our live ship-to-shore interactions were also used to address local education priorities. In the last three years, this collaboration has connected E/V *Nautilus* with 235 classrooms and community events throughout Hawaiʻi. Thanks to the support of Kānaka ʻŌiwi onboard and language facilitators ashore, 34 live interactions were conducted in ʻōlelo Hawaiʻi.

Expeditions are only part of the knowledge-creation process. This partnership continues through the collaborative work of appropriately sharing the story of what we learned. OET will continue working closely with the Papahānaumokuākea Native Hawaiian Cultural Working Group Nomenclature subcommittee and the broader Native Hawaiian community to develop names for biological and geological features revealed through the eight E/V *Nautilus* expeditions to the Papahānaumokuākea Marine National Monument. Each one of these names aims to appropriately honor the intimate genealogical relationship between Kānaka ʻŌiwi and the environment.

As we braid cultural knowledge into science and exploration, we shift into a worldview that emphasizes kinship, and perceives the natural world as subjects, not objects. From this perspective, current extractive practices and entitlement inherent within the Western-scientific sample collection process is a conversation to move forward. We cannot take without giving back as reciprocity is fundamental to the collective well-being of humans and nature. Deep reflection is needed to co-develop sampling guidelines that reflect kinship: when a sample is collected, you inherit guardianship and must think about access, protocols for use and reuse, data sharing, and repatriation. While conducting research in Indigenous spaces, it is essential that scientists be accountable to the communities they work in and derive their data from by giving back in some way. Equitable partnerships must always be able to answer how research will benefit the community, based on their self-identified priorities and needs.

This partnership sets a strong foundation for empowering Indigenous communities, who were the original stewards and experts of these oceans, to expand upon knowledge and relationships to deep-sea ecosystems. We hope that this framework presents an inspiring opportunity to initiate change toward more ethical and well-rounded research. This collaboration was made possible by the dedication of the Papahānaumokuākea Native Hawaiian Cultural Working Group, staff of NOAA Papahānaumokuākea Marine National Monument, the NOAA Office of National Marine Sanctuaries, the ʻIke Moana hui, the National Marine Sanctuary Foundation, and the OET. At-sea internships and fellowships were supported by the Office of Naval Research STEM Program.

BIOLOGICAL SAMPLE ARCHIVES AT THE MUSEUM OF COMPARATIVE ZOOLOGY

Adam Baldinger

This year marked the 10th anniversary of the successful partnership between the Ocean Exploration Trust and the Museum of Comparative Zoology at Harvard University. Since 2013, nearly 4,500 biological specimens collected on 48 different E/V *Nautilus* expeditions have been accessioned at the Museum of Comparative Zoology, housed within the collections of Ichthyology, Invertebrate Zoology, Malacology, and Vertebrate Paleontology (Figure 1). In addition to permanently curating these rich specimen collections, the Museum of Comparative Zoology provides opportunities for qualified researchers from around the world to access them, thereby enabling follow-on research and discovery.

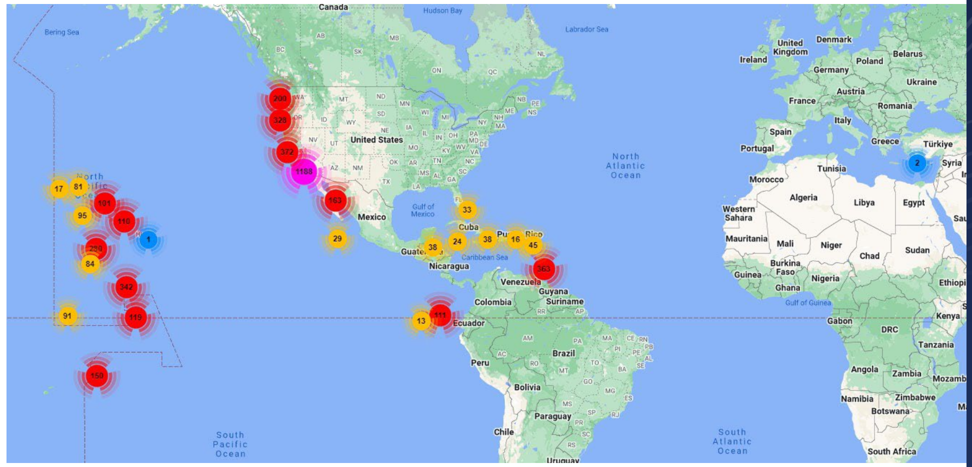


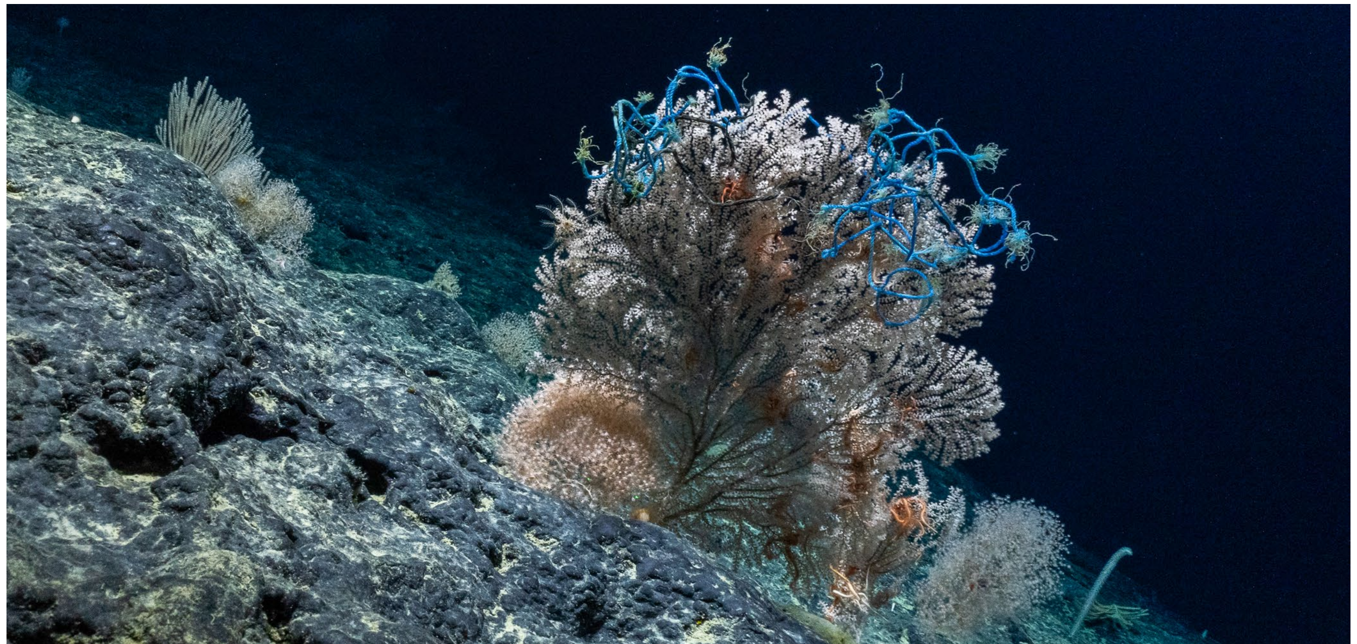
Figure 1. Map showing the geographic distribution of specimens collected by the E/V *Nautilus* since 2013 that have been accessioned into the collections of the Museum of Comparative Zoology.

In 2023, biological specimens collected on four separate E/V *Nautilus* expeditions (NA149, NA153, NA154, and NA156) were accessioned at the Museum of Comparative Zoology, in the Invertebrate Zoology and Malacology collections. Specimens arrived at the museum shortly after each expedition concluded, along with locality data, preliminary identifications, and other relevant metadata which were used to catalog the specimens into our museum-wide database MCZbase. This year, Museum of Comparative Zoology staff members joined E/V *Nautilus* expeditions at sea, during which they helped improve workflows as samples transitioned from the field to the museum. Giuliana Fillion sailed on the NA149 expedition, whereas Paula Rodríguez-Flores sailed on NA153.

Figure 2. The new squat lobster species *Munidopsis nautilus*, which was recently described by Museum of Comparative Zoology post-doctoral fellow Paula Rodríguez-Flores and colleagues to honor E/V *Nautilus* and its many contributions to science (photo credit: Paula Rodríguez-Flores).

Biological specimens collected on E/V *Nautilus* expeditions augment other museum collections quite well. Many of the E/V *Nautilus* specimens are either not previously represented in our collections, or represent a new locality from which a given species is found. From the NA149 expedition alone, specimens within 29 different taxonomic families were accessioned into our collections. Scientists from the Museum of Comparative Zoology and elsewhere utilize these specimens to complement ongoing research projects, such as the Documenting Marine Biodiversity through Digitization of Invertebrate Collections project funded by the National Science Foundation. Additionally, several new species have recently been described using E/V *Nautilus* specimens that are housed at the Museum of Comparative Zoology. In 2023, Museum of Comparative Zoology post-doctoral fellow Paula Rodríguez-Flores and colleagues described several new squat lobster species. One of these new species, *Munidopsis nautilus* (Figure 2) was named to honor the E/V *Nautilus* and its many contributions to science.

Specimen records in the museum-wide database MCZbase are accessible to anyone with an Internet connection, and are also shared with and accessible from several other data aggregators such as iDigBio, GBIF, and GenBank. A Named Group page was recently developed that is associated with MCZbase and enables public access to information about E/V *Nautilus* and the Ocean Exploration Trust. This Named Group site lists specimen records, including searchable links enabling the breakdown of records by taxa, geography, ocean regions, expeditions numbers, distribution maps, images, videos, and specimens cited in scientific publications.



OPEN-ACCESS TO E/V *NAUTILUS* GEOLOGICAL SAMPLES AT THE UNIVERSITY OF RHODE ISLAND

MARINE GEOLOGICAL SAMPLES LABORATORY

Katherine A. Kelley, Danielle Cares, and Rebecca S. Robinson

ROV *Hercules* uses a variety of tools, including push cores, scoops, and manipulators to recover geological samples from the seafloor. These samples provide vital physical records of the geological history of marine landscapes viewed through the lenses of the ROV's cameras, and serve as the foundations for critical post-expedition scientific research. Permanent, open-access archival of these materials is therefore essential. The Marine Geological Samples Laboratory at the University of Rhode Island Graduate School of Oceanography operates under joint funding from the National Science Foundation and the NOAA Ocean Exploration Cooperative Institute to provide long-term archival for samples collected on E/V *Nautilus* expeditions. These samples are assigned International Generic Sample Numbers (IGSNs), and are also publicly listed at the System for Earth and Extraterrestrial Sample Registration (SESAR) and the NOAA Index to Marine and Lacustrine Geological Samples (IMLGS). In 2023, the Marine Geological Samples Laboratory archived 198 new rock and sediment samples collected by ROV *Hercules* on E/V *Nautilus* expeditions to Kingman Reef and Palmyra Atoll (NA149), Johnston Atoll (NA153), the Papahānaumokuākea Marine National Monument (NA154), and the Geologists Seamounts (NA156). The Marine Geological Samples Laboratory recently began highlighting specimens in our collections via our Instagram account @URIMGSL.

Figure 1. Cut pieces of sample NA149-094-C-MGSL, a hyaloclastite made up of volcanic fragments (now weathered to rusty orange) that are cemented together with white calcium carbonate. Black ferromanganese crust coats the outer surfaces of the rock (photo credit: Danielle Cares).

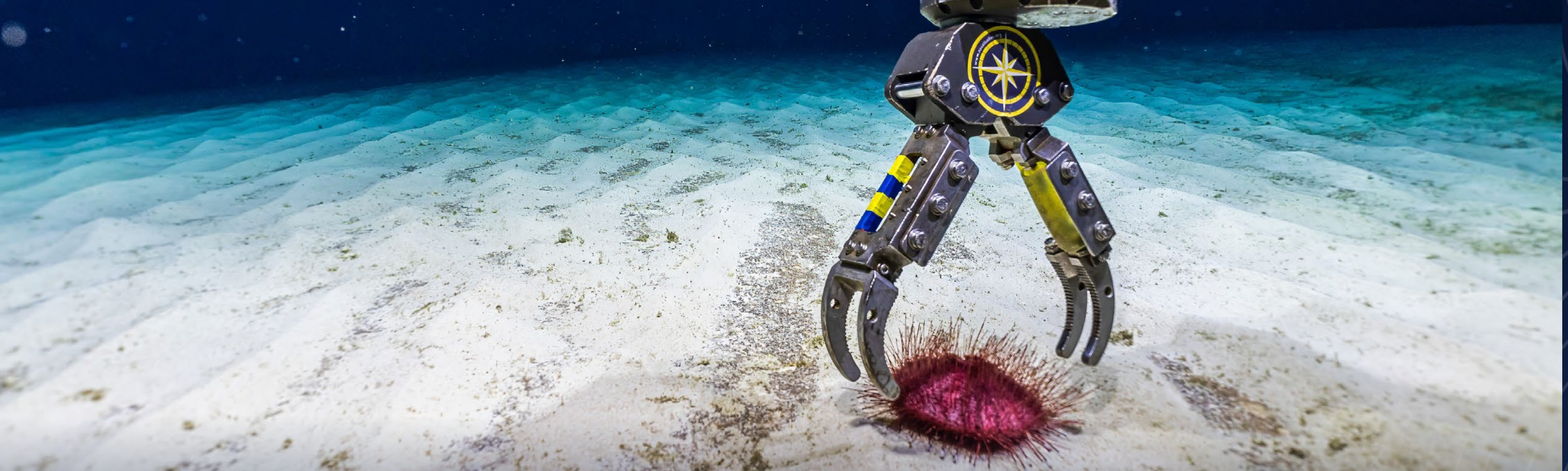
Figure 2. Close-up view of peperite sample NA153-085-C-MGSL, showing carbonate sediment (light) intermingled with weathered volcanic fragments (orange/brown). Vertical field of view is ~8 centimeters (photo credit: Sandra Slead).

Figure 3. Cut surface of sample NA154-073-C-GSO, showing the gas bubbles from the lava, including a zone where the bubble cavities are now filled with calcium carbonate (light) (photo credit: Sandra Slead).

Samples recovered during the NA149 expedition included numerous rocks encrusted with variable thicknesses of ferromanganese crust. This crust is an extremely slow-growing secondary mineralization that covers hard surfaces exposed to seawater over geologic time, and it is a common feature of lava and other rocks that are exposed at older seamounts. The rocks beneath these crusts include variably altered lava, carbonate sediment, and hyaloclastite (Figure 1), which is a breccia made up of glassy volcanic fragments. Samples collected on the NA153 expedition returned a similar trove of ferromanganese-encrusted lavas and sediments, but also included several specimens of an unusual rock called a peperite (Figure 2). Peperites form when hot lava comes into contact with marine sediments, effectively baking the sediments and fragmenting the lava into small pieces, while cementing the two materials together at their interface. The NA154 expedition also recovered numerous samples of variably weathered, ferromanganese-encrusted lava. Many of the lava samples from that expedition contained abundant gas bubbles (vesicles), which have been filled in with calcium carbonate in the time since the lava originally flowed and cooled (Figure 3). The NA156 expedition recovered some nice examples of ferromanganese nodules, which form similarly to ferromanganese crusts but enclose smaller particles within the near-surface sediments on the seafloor.

A recent highlight occurred when staff at the Marine Geological Samples Laboratory discovered a unique *Megalodon* tooth specimen (Figure 4) among a scoop of ferromanganese nodules from the 2022 expedition to Johnston (NA141) that continues to capture the public's attention. The *Megalodon* was a large shark species that lived in the global oceans between 23 and 3.6 million years ago. The NA141 specimen marks the first *in situ* observation and sampling of a *Megalodon* tooth from the deep ocean seafloor, with a newly-published study detailing its preservation and geological context. Samples from these and numerous other marine geological expeditions are openly available upon request from the Marine Geological Samples Laboratory.

Figure 4. Image of sample NA141-006-01-MT, a fossil tooth of a *Megalodon* shark that was recovered in a scoop of ferromanganese nodules collected at a depth of 3,090 meters on an unnamed seamount located 350 kilometers southeast of Johnston Atoll. The tooth is about 7 centimeters long.



2023 SCIENCE PUBLICATIONS
FROM E/V *NAUTILUS* EXPEDITIONS

Daniel Wagner

A major goal of the Ocean Exploration Trust and E/V *Nautilus* expeditions is to provide a rich foundation of publicly-accessible information to catalyze follow-on exploration, research, and management activities. In addition to this report summarizing accomplishments from the 2023 E/V *Nautilus* field season, a total of 56 science publications were published in 2023 that used data collected by E/V *Nautilus* in previous years. These publications cover a wide range of topics and scientific disciplines, thereby highlighting the highly interdisciplinary nature of our work.

Ackerman A, Yarincik K, Murphy S, Cetinić I, Fundis AT, Miller A, Shroyer E, Busse A, Covington QD, DeSilva A, Haupt A, Johnson L, Lee C, Lorenzoni L, Murphy B, Ramarui J, Rosenheim B, Steinberg D (2023). Know before you go: a community-derived approach to planning for and preventing sexual harassment at oceanographic field sites. Oceanography 36(1): 38-43. https://doi.org/10.5670/oceanog.2023.112

Baco AR, Parrish FA, Auscavitch S, Cairns S, Mejia-Mercado BE, Biede V, Morgan N, Roark EB, Brantley WB (2023). Deep-sea corals of the North and Central Pacific seamounts. In: Cold-Water Coral Reefs of the World. Cordes E, Mienis F (eds.) pp. 261-293. https://link.springer.com/chapter/10.1007/978-3-031-40897-7_10

Baco AR, Ross R, Althaus F, Amon D, Bridges AEH, Brix S, Buhl-Mortensen P, Colaco A, Carreiro-Silva M, Clark MR, Du Preez C, Franken M, Gianni M, Gonzalez-Mirelis G, Hourigan T, Howell K, Levin LA, Lindsay DJ, Molodtsova TN, Morgan N, Morato T, Mejia-Mercado BE, O'Sullivan D, Pearman T, Price D, Robert K, Robson L, Rowden AA, Taylor J, Taylor M, Victorero L, Watling L, Williams A, Xavier JR, Yesson C (2023). Towards a scientific community consensus on designating Vulnerable Marine Ecosystems from imagery. PeerJ 11: e16024. https://doi.org/10.7717/peerj.16024

Barnhill KA, Vinha B, Smith AJ, de Jonge DSW, Gaurisas DY, Segura RM, Madureira P, Albuquerque M, Huvenne VAI, Orejas C, Gunn V (2023). Ship-to-shore training for active deep-sea capacity development. ICES Journal of Marine Science 80(6): 1619-1628. https://doi.org/10.1093/icesjms/fsad088

Bravo ME, Brandt MI, van der Grient JMA, Dahlgren TG, Esquete P, Gollner S, Jones DOB, Levin LA, McClain CR, Narayanaswamy BE, Sutton T, Victorero L, Cordes EE (2023). Insights from the management of offshore energy resources: toward an ecosystem-services based management approach for deep-ocean industries. Frontiers in Marine Science 9: 994632. https://doi.org/10.3389/fmars.2022.994632

Brenneis G, Wagner D (2023). Mating observation of giant sea spiders (Pycnogonida: Colossendeidae). Marine Biodiversity 53:45. https://doi.org/10.1007/s12526-023-01350-3

Butterfield DA, Walker SL, Baumberger T, Beeson J, Resing J, Merle SG, Antriasian A, Roe K, Lu GS, Barrett P, Chadwick WW (2023). The PMEL Earth-Ocean Interactions Program: beyond vents. Oceanography 36(2-3: 206-211. https://doi.org/10.5670/oceanog.2023.229

Chan EW, Alanis BA, German CR, Lim DSS, Breier JA (2023). Oxygen and hydrogen isotopic evidence that Kamaʻehuakanaloa (Lōʻihi) Seamount hydrothermal systems are recharged by deep Pacific seawater. Deep Sea Research Part I: Oceanographic Research Papers 197: 104049. https://doi.org/10.1016/j.dsr.2023.104049

Crosby A, Orenstein EC, Poulton SE, Bell KLC, Woodward B, Ruhl H, Katija K, Forbes AG (2023). Designing ocean vision AI: an investigation of community needs for imaging-based ocean conservation. CHI '23: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems 535: 1-16. https://doi.org/10.1145/3544548.3580886

Cummings S, Ardor Bellucci LM, Seabrook S, Raineault NA, McPhail KL, Thurber AR (2023). Variations and gradients between methane seep and off-seep microbial communities in a submarine canyon system in the Northeast Pacific. PeerJ 11: e15119. https://peerj.com/articles/15119/

Di Capua A, De Rosa R, Kereszturi G, Le Pera E, Rosi M, Watt SFL (2023). Volcanically derived deposits and sequences: a unified terminological scheme for application in modern and ancient environments. Geological Society, London, Special Publications 520: 11-27. https://doi.org/10.1144/SP520-2021-201

Dinn C, Ott B, Marmen MB, Steeves R, Côté G, Hayes V, Nozères C, Everett MV, Powell A, Chu JWF (2023). Two large structure-forming sponges from opposite North American coasts: a taxonomic review of Arctic-Pacific *Mycale* (*Mycale*) *loveni* and the description of a new Arctic-Atlantic *Mycale*. Canadian Journal of Zoology 101(9): 807-823. https://doi.org/10.1139/cjz-2023-0011

Duncan E, Adams C, Caldow C, Chavez E, Clarke E, Coleman H, Everett M, Hourigan T, Laidig T, Waddell J, Winship A (2023). NOAA West Coast Deep-Sea Coral Initiative 2018-2021: Final Report. NOAA Technical Memorandum NMFS-OHC-12: 70 pp. https://library.oarcloud.noaa.gov/noaa_documents.lib/NMFS/TM_NMFS_OHC/TM_NMFS_OHC_12.pdf

Escobar-Briones E, Álvarez-Sánchez LF (2023). Citizen science for deep ocean biodiversity: a crowdsourcing tool in support of conservation. Mexican Fauna in the Anthropocene: 581-593. https://doi.org/10.1007/978-3-031-17277-9_27

Georgieva MN, Rimskaya-Korsakova NN, Krolenko VI, Van Dover CL, Amon DJ, Copley JT, Plouviez S, Ball B, Wiklund H, Glover AG (2023). A tale of two tubeworms: taxonomy of vestimentiferans (Annelida: Siboglinidae) from the Mid-Cayman Spreading Centre. Invertebrate Systematics 37(3): 167-191. https://doi.org/10.1071/IS22047

Gerringer ME, Ismail Y, Cannon KA, Camilo Hernandez A, Gonzales Peralta F, Bohen R, Cartwright JC, Feasley A, Fregosi L, Lehman H, Niles H, Quay J, Sherpa N, Woodworth BH, Cantwell K (2023). Deep-sea biology in undergraduate classrooms: open access data from remotely operated vehicles provide impactful research experiences. Frontiers in Marine Science 10: 1033274. https://doi.org/10.3389/fmars.2022.1033274

Goffredi SH, Panossian B, Brzechffa C, Field N, King C, Moggioli G, Rouse GW, Martín-Durán JM, Henry LM (2023). A dynamic epibiont community associated with the bone-eating polychaete genus *Osedax*. American Society for Microbiology 14(4): e03140-22. https://doi.org/10.1128/mbio.03140-22

Govindarajan AF, Adams A, Allan E, Herrera S, Lavery A, Llopiz J, McCartin L, Yoerger DR, Zhang W (2023). Advances in environmental DNA sampling for observing ocean twilight zone animal diversity. Oceanography 36(1): 80-86. https://www.jstor.org/stable/27217388

Hutto SH, George D, Tezak S (2023). Blue carbon in marine protected areas: Part 3, an evaluation of sedimentary carbon stocks in Greater Farallones and Cordell Bank National Marine Sanctuaries. National Marine Sanctuaries Conservation Series ONMS-23-06. https://repository.library.noaa.gov/view/noaa/52098

Kennedy BRC, Rotjan RD (2023). Mind the gap: comparing exploration effort with global biodiversity patterns and climate projections to determine ocean areas with greatest exploration needs. Frontiers in Marine Science 10: 1219799. https://doi.org/10.3389/fmars.2023.1219799

Laso-Pérez R, Wu F, Crémière A, Speth DR, Magyar JS, Zhao K, Krupovic M, Orphan VJ (2023). Evolutionary diversification of methanotrophic ANME-1 archaea and their expansive virome. Nature Microbiology 8: 231-245. https://doi.org/10.1038/s41564-022-01297-4

Latchman JL, Dondin FJY, Robertson REA, Stewart R, Smith P, Lynch LL, Ramsingh C, Nisha N, Ramsingh H, Juman I, Edwards S, Ash C (2023). Contrasting T-phase and P-wave patterns from the 2015 and 2017 eruptions of the submarine volcano Kick-'em-Jenny: influence of cardinal direction on recorded first phase arrival. Bulletin of the Seismological Society of America 113(5): 2056–2068. https://doi.org/10.1785/0120220101

Lawal MA, Bialik OM, Lazar M, Waldmann ND, Foubert A, Makovsky Y (2023). Modes of gas migration and seepage on the salt-rooted Palmahim Disturbance, southeastern Mediterranean. Marine and Petroleum Geology 153: 106256. https://doi.org/10.1016/j.marpetgeo.2023.106256

Lawal MA, Findlay R, Bialik O, Neuman A, Waldermann N, Makovsky Y (2023). Using multilevel composition to map rare seafloor gas-seepage habitats of the Palmahim disturbance, southeastern Mediterranean Sea. NSG2023 29th European Meeting of Environmental and Engineering Geophysics: 1-5. https://doi.org/10.3997/2214-4609.202320163

Louden SI, Kessler JD (2023). The emission of low pH water from Gulf of Mexico seeps as revealed by $\delta^{13}C$-CO_2 and methane oxidation data. Environmental Science Advances 2: 1600-1606. https://doi.org/10.1039/d3va00117b

Malcher F, White P (2023). Acoustic monitoring techniques for subsea leak detection: a review of the literature. National Physical Laboratory Report AC21: 22 pp.https://eprintspublications.npl.co.uk/9781/1/AC%2021.pdf

Mayer LM (2023). Uncrewed surface systems facilitating a new era of global ocean exploration. The International Hydrographic Review 29(1): https://ihr.iho.int/articles/uncrewed-surface-systems-facilitating-a-new-era-of-global-ocean-exploration/

Milesi V, Shock E, Seewald J, Trembath-Reichert E, Sylva SP, Huber JA, Lim DSS, German CR (2023). Multiple parameters enable deconvolution of water-rock reaction paths in low-temperature vent fluids of the Kamaʻehuakanaloa (Lōʻihi) seamount. Geochimica et Cosmochimica Acta 348: 54-67. https://doi.org/10.1016/j.gca.2023.03.013

Mulder T, Cavailhes T, Hanquiez V, Gillet H, Recouvreur A, Fabregas N (2023). Giant deep submarine depressions: a combined dissolution-mechanical process along carbonate margins. GSA Bulletin 135(3-4): 743-752. https://doi.org/10.1130/B36142.1

Murali R, Yu H, Speth DR, Wu F, Metcalfe KS, Crémière A, Laso-Pérez R, Malmstrom RR, Goudeau D, Woyke T, Hatzenpichler R, Chadwick GL, Connon SA, Orphan VJ (2023). Physiological potential and evolutionary trajectories of syntrophic sulfate-reducing bacterial partners of anaerobic methanotrophic archaea. PLOS Biology 21(9): e3002292. https://doi.org/10.1371/journal.pbio.3002292

Osman EO, Vohsen SA, Girard F, Cruz R, Glickman O, Bullock LM, Anderson KE, Weinnig AM, Cordes EE, Fisher CR, Baums IB (2023). Capacity of deep-sea corals to obtain nutrition from cold seeps aligned with microbiome reorganization. Global Change Biology 29(1): 189-205. https://doi.org/10.1111/gcb.16447

Pollerspöck J, Cares D, Ebert DA, Kelley KA, Pockalny R, Robinson RS, Wagner D, Straube N (2023). First *in situ* documentation of a fossil tooth of the megatooth shark *Otodus* (*Megaselachus*) *megalodon* from the deep sea in the Pacific Ocean. Historical Biology. https://doi.org/10.1080/08912963.2023.2291771

Redick MA, Cummings ME, Neuhaus GF, Ardor Bellucci LM, Thurber AR, McPhail KL (2023). Integration of untargeted metabolomics and microbial community analyses to characterize distinct deep-sea methane seeps. Frontiers in Marine Science 10: 1197338. https://doi.org/10.3389/fmars.2023.1197338

Rodriguez Flores PC, Schnabel KE (2023). New records and species of deep-sea squat lobsters (Galatheoidea, Munidopsidae) from the Hawaiian Archipelago: an integrative approach using micro-CT and barcodes. PeerJ 11: e14956. https://doi.org/10.7717/peerj.14956

Rodriguez-Flores PC, Seid CA, Rouse GW, Giribet G (2023). Cosmopolitan abyssal lineages? A systematic study of East Pacific deep-sea squat lobsters (Decapoda: Galatheoidea: Munidopsidae). Invertebrate Systematics 37(1).14-60. https://doi.org/10.1071/IS22030

Rotjan RD, Bell KLC, Huber JA, Wheat CG, Fisher AT, Sylvan RL, McManus J, Bigham KT, Cambronero-Solano S, Cordier T, Goode S, Leonard J, Murdock S, Paula FS, Ponsoni L, Roa-Varón A, Seabrook S, Shomberg R, Van Audenhaege L, Orcutt BN (2023). COBRA Master Class: providing deep-sea expedition leadership training to accelerate early career advancement. Frontiers in Marine Science 10: 1223197. https://doi.org/10.3389/fmars.2023.1223197

Rudebusch JA, Prouty NG, Conrad JE, Watt JT, Kluesner JW, Hill JC, Miller NC, Watson SJ, Hillman JIT (2023). Diving deeper into seep distribution along the Cascadia convergent margin, United States. Frontiers in Earth Science 11: 1205211. https://doi.org/10.3389/feart.2023.1205211

Samonte G, Damato N, Peau AL, Brighouse G, Que N, Gaoteote I, Shea R, Schwarzmann D, Flem L (2023). National Marine Sanctuary of American Samoa community profile, 2010-2019. National Marine Sanctuaries Conservation Series ONMS-23-08. https://repository.library.noaa.gov/view/noaa/55671

Selig GM, Drazen JC, Auster PJ, Mundy BC, Kelley CD (2023). Distribution and structure of deep-sea demersal fish assemblages across the central and western Pacific Ocean using data from undersea imagery. Frontiers in Marine Science 10: 1219368. https://doi.org/10.3389/fmars.2023.1219368

Sotomayor A, Balbas A, Konrad K, Koppers AAP, Konter JG, Wanless VD, Hourigan TF, Kelley C, Raineault NA (2023). New insights into the age and origin of two small Cretaceous seamount chains proximal to the Northwestern Hawaiian Ridge. Geosphere 19(2): 383-405. https://doi.org/10.1130/GES02580.1

Soule A, Kennedy B, Coleman DF, Sobron P, Smith D, Cook M, Zaccaria J, Wagner D (2023). Exploring deep-sea habitats near Kingman Reef & Palmyra Atoll. Deep-Sea Life 21: 11-12. https://www.dosi-project.org/wp-content/uploads/Deep-Sea-Life-Issue-21.pdf

Sowers D, Zaccaria J (2023). Ocean Exploration Trust - mapping and exploring the global ocean for 15 years. Sea Technology (June 2023): 15-20. https://lsc-pagepro.mydigitalpublication.com/publication/?m=60787&i=794422&p=14

Stewart JA, Robinson LF, Rae JWB, Burke A, Chen T, Li T, de Carvalho Ferreira ML, Fornari DJ (2023). Arctic and Antarctic forcing of ocean interior warming during the last deglaciation. Scientific Reports 13: 22410. https://doi.org/10.1038/s41598-023-49435-0

Sun Y-J, Robinson LF, Parkinson IJ, Stewart JA, Lu W, Hardisty DS, Liu Q, Kershaw J, LaVigne M, Horner TJ (2023). Iodine-to-calcium ratios in deep-sea scleractinian and bamboo corals. Frontiers in Marine Science 10: 1264380. https://doi.org/10.3389/fmars.2023.1264380

Sunkara V, McKenna J, Kar S, Iliev I, Bernstein DN (2023). The Gulf of Mexico in trouble: big data solutions to climate change science. Frontiers in Marine Science 10: 1075822. https://doi.org/10.3389/fmars.2023.1075822

Ten Bring US, Chaytor JD, Flores CH, Wei Y, Detmer S, Lucas LC, Andrews BD, Georgiopoulou A (2023). Seafloor observations eliminate a landslide as the source of the 1918 Puerto Rico Tsunami. Bulletin of Seismological Society of America 113(1): 268-280. https://doi.org/10.1785/0120220146

Versteegh EAA, Van Dover CL, Van Audenhaege L, Coleman M (2023). Multiple nutritional strategies of hydrothermal vent shrimp (*Rimicaris hybisae*) assemblages at the Mid-Cayman Rise. Deep Sea Research Part I: Oceanographic Research Papers 192: 103915. https://doi.org/10.1016/j.dsr.2022.103915

Vlach DS (2023). An illustrated guide to the Southern California Borderland: 111 pp. https://escholarship.org/uc/item/1hg7v0q0

Wagner D (2023). New frontiers in ocean exploration: the E/V *Nautilus* 2022 field season. Oceanography Supplement 36(2). https://doi.org/10.5670/oceanog.2023.s2

Wagner D (2023). 2022 E/V *Nautilus* field season overview. Deep-Sea Life 20: 4-6 https://www.dosi-project.org/wp-content/uploads/DSL20_final2_small.pdf

Walker SL (2023). Spotlight on MAPR - PMEL's miniature autonomous plume recorder. Oceanography 36(2-3): 212-216. https://www.jstor.org/stable/27257901

Weidlich R, Bialik OM, Rüggeberg A, Grobéty B, Vennemann T, Neuman A, Makovsky Y, Foubert A (2023). Occurrence and genesis of cold-seep authigenic carbonates from the south-eastern Mediterranean Sea. The Depositional Record 9: 844-870. https://doi.org/10.1002/dep2.239

Wicksten MK, Konway KW (2023). The Chirostyloidea of the Northeastern Pacific: host associations, range extensions and a new species (Decapoda: Anomura). Zootaxa 5284(1):10 https://doi.org/10.11646/zootaxa.5284.1.7

Yamazaki M (2023). Contemporary philosophy for maritime archaeology: flat ontologies, oceanic thought, and the Anthropocene (2022). Shima 17(2): 278-283. https://shimajournal.org/article/10.21463/shima.201.pdf

Zegkinoglou NN, Mathur R, Kilias SP, Godfrey L, Pletsas V, Nomikou P, Zaronikola N (2023). Boiling-induced extreme Cu isotope fractionation in sulfide minerals forming by active hydrothermal diffusers at the Aegean Kolumbo volcano: evidence from *in situ* isotope analysis. Geology 511(11): 1072-1076. https://doi.org/10.1130/G51404.1

Zvi-Kedem T, Vintila S, Kleiner M, Tchernov D, Rubin-Blum M (2023). Metabolic handoffs between multiple symbionts may benefit the deep-sea bathymodioline mussels. ISME Communications 3: 48. https://doi.org/10.1038/s43705-023-00254-4

WHAT IS NEXT

Allison Fundis, Daniel Wagner, and Robert D. Ballard

While E/V *Nautilus* expeditions in 2023 surveyed a wide range of habitats, geological features, and underwater cultural heritage sites, vast areas across the Pacific Ocean remain completely unexplored. E/V *Nautilus* expeditions in the coming years will continue filling the large knowledge gaps that remain across the Pacific via seafloor mapping, ROV explorations, and deploying emerging exploration technologies. This will include working in geographies where we have previously deployed E/V *Nautilus*, including the Main Hawaiian Islands, the Jarvis Unit of the Pacific Remote Islands Marine National Monument, and British Columbia. However, our 2024 expeditions will also involve working in new geographies for E/V *Nautilus*, like Palau, or in geographies where the ship has not operated since 2019, like the US Exclusive Economic Zone around Howland Island, Baker Island, and American Samoa.

In addition to basic exploration, our 2024 expeditions will continue to support the integration of emerging exploration technologies onto E/V *Nautilus* operations, particularly those from affiliate institutions of the NOAA Ocean Exploration Cooperative Institute. Building on the recent success of integrating ASV *DriX*, AUV *Mesobot*, and the Deep Autonomous Profiler into E/V *Nautilus* operations, expeditions in 2024 will continue to expand the range and independence of these vehicles from E/V *Nautilus*, and thereby seek to catalyze the force-multiplier of multi-vehicle exploration. In addition to these emerging technologies, 2024 expeditions will also feature deployments of various other advanced technologies developed at Woods Hole Oceanographic Institution in collaboration with other partners, including AUV *Sentry*, as well as an eDNA multi-sampler and methane sensor that will be mounted onto ROV *Hercules* on select dives.

In addition to the above-mentioned efforts aimed at advancing the goals of the NOAA Ocean Exploration Cooperative Institute, our 2024 field season will include dedicated expeditions to support projects funded by Ocean Networks Canada and the Bureau of Ocean Energy Management. Building on the successful partnership with Ocean Networks Canada that started in 2015, E/V *Nautilus* will return to the waters offshore British Columbia to support the maintenance of various sensors, cables, and instruments that make up the Ocean Networks Canada NEPTUNE cabled observatory. Similarly, building on the success of the 2023 inter-agency collaboration expedition to Hawai'i, in 2024, E/V *Nautilus* will map and characterize abyssal plains in American Samoa to support science priorities of the Bureau of Ocean Energy Management, US Geological Survey, and NOAA.

As in previous years, partnerships will remain a centerpiece of our exploration efforts in 2024 and beyond. Building on its ongoing collaborations with NOAA Ocean Exploration, NOAA's Ocean Exploration Cooperative Institute, Ocean Networks Canada, Office of Naval Research, National Geographic Society, Ocean Census, National Marine Sanctuary Foundation, Papahānamokuākea Marine National Monument, National Marine Sanctuary of American Samoa, Palau International Coral Research Center, and many others, OET will seek to continue exploring across the Pacific Ocean, and meaningfully connect this work to audiences across the globe, particularly those from the geographies where E/V *Nautilus* will operate.

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- Seabed 2030
- Tuskegee University
- UN Decade of Ocean Science for Sustainable Development
- University of New Hampshire
- University of Rhode Island
- University of Southern Mississippi
- Woods Hole Oceanographic Institution

Education, Outreach & Media Partners

- CITGO Petroleum Corporation
- National Marine Sanctuary Foundation
- NOAA Educational Partnership Program
- NOAA Ocean Exploration
- NOAA Office of National Marine Sanctuaries
- NSF STEMSEAS Program
- Office of Naval Research
- Phil Stephenson Foundation


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