The Explorer Model: Lessons from 10 Years of Community-led Ocean Exploration & Open Data

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NOAA

Introduction

The momentum behind ocean exploration is building. The science, tools, and public support for underwater exploration has greatly expanded in the last two decades. As a global community of explorers, we are more connected than ever. We have entered a golden age of telepresence where increased video streaming capabilities, high-bandwidth satellite connections, and the ubiquity of laptops and smartphones are capable of bringing live ocean exploration to the public. Every year, more philanthropic organizations and industry partners turn their attention to deep-sea exploration to improve global understanding of the ocean. The United States has developed a National Strategy for Mapping, Exploring, and Characterizing (NOMEC) the U.S. Exclusive Economic Zone as described in the 2019 Presidential Memorandum on Ocean Mapping of the United States Exclusive Economic Zone and the Shoreline and Nearshore of Alaska. Through Seabed 2030, the Nippon Foundation-General Bathymetric Chart of the Oceans (GEBCO) program issued a challenge to map the world's ocean by 2030, revitalizing global interest in seafloor mapping. Though exploration of the deep sea is a challenging mission, policy, technology, and public interest are quickly advancing to meet the task.

The National Oceanic and Atmospheric Administration (NOAA) Office of Ocean Exploration and Research (OER) is the only U.S. federal program dedicated to exploring our ocean while working in partnership to address prominent gaps in our basic understanding of the deep sea (> 200 metres). Through partnerships, a variety of funding mechanisms, and at-sea operations, OER delivers critical information about the deep ocean to managers, decision makers, scientists, and the public. OER's operations onboard NOAA Ship *Okeanos Explorer* have transformed how we collaborate as an ocean exploration community, building a coalition of academic scientists, government agencies, private and non-profit organizations, and other partners. Working closely with this community, OER assesses knowledge gaps in deep-sea exploration and constructs expeditions to address the most pressing needs. We explore poorly understood areas by collecting data to establish a foundation of publicly available information.

In 2019, OER celebrated 10 years of exploration with *Okeanos Explorer*. The development of a unique operating model – what we now call the "Explorer Model" after the ship it was first demonstrated on – was fundamental to the success of this decade of expeditions. The Explorer Model is community-driven exploration employing telepresence to engage a broad spectrum of the science and resource management communities, resulting in publicly available data that catalyzes future deep-sea research and discovery. More than just telepresence-enabled exploration, this model is about bringing together the science and resource management communities to collaborate in real time and explore areas of the deep sea where our understanding is lacking. Explorer Model expeditions also share the excitement of discovery with the public, bringing ocean exploration to an audience that would not otherwise have the chance to experience it for themselves.

Each year, we have grown and adapted the Explorer Model based on lessons learned and to take advantage of new opportunities. In 2015, we reached an inflection point with the beginning of the Campaign to Address Pacific Science, Technology, and Ocean Needs (CAPSTONE). CAPSTONE would not only become one of the largest ocean exploration campaigns undertaken by the U.S. government, but would also solidify the Explorer Model's core concept of operations and greatly expand our community network and stakeholder group. When OER first started expeditions aboard *Okeanos Explorer* in 2010, science teams were composed of 10-20 people participating from Exploration Command Centers, which were connected to the ship via specialized equipment and an Internet-2 connection.

Progressive infrastructure investments since then have enabled shore-based teams to participate from their home or local institution using a standard Internet connection and any Internet-enabled device. Without the barrier of specialized equipment, science teams routinely swell above 100 participants from around the world, connecting a community of explorers well beyond what any one research vessel could accommodate on board. During CAPSTONE, OER brought new collaboration tools online to facilitate crowd-sourced scientific annotations and improve our ability to gather input from a broader audience. As we made it easier for researchers to participate, a new contingent of scientists joined, bringing with them a wide-ranging network that helped to expand the model organically. *Okeanos Explorer* was designed to be America's beacon for ocean exploration, and one of her lasting contributions will be galvanizing a new approach for deep-sea exploration.

The Explorer Model

The various components of the Explorer Model include a collaborative approach to priority identification, strategic partnerships, the ability to pool resources, open and free access to data, and continuous engagement of stakeholders. With expeditions operating under this model, OER seeks to go beyond the objectives or research questions of individual scientists and instead focus on the collective needs of the community. Expedition Coordinators, instead of Chief Scientists, manage each mission to develop partnerships, facilitate collaboration, and collect high-quality data to address exploration goals. Expeditions are designed to complement other ongoing research projects in the area, serving as a force multiplier and building awareness of broader exploration needs of the region. Strategic exploration guides Explorer Model expeditions, systematically building upon each other to address large data gaps and leverage resources from one project to another (e.g., Figure 1). From expedition conception to completion, the engagement of a broad user base provides a diversity of expertise and perspectives, creates buy-in from the community, and allows us to conduct multidisciplinary expeditions.

What sets these expeditions apart from traditional research endeavours and other telepresence-enabled initiatives is how OER collaboratively plans its missions. Input is solicited at multiple levels (e.g., federal agencies, state and local governments, philanthropic organizations, industry partners, academic researchers, etc.), starting several years in advance of a field effort through workshops, white papers, consultations with partners, webinars, and broad invitations to submit exploration targets (Figure 2). OER then uses this information to build a regional multiyear campaign structure that guides the design of individual expeditions to accomplish the overarching goals. The final step is to conduct collaborative mission planning with the broad science community and refine priorities into specific cruise plans that will complement future planned efforts in the region.

The concept of coordinated campaigns evolved over time, in tandem with emerging opportunities. What started as capitalizing on opportunistic platforms to increase bathymetric coverage during the Atlantic Canyons Undersea Mapping (ACUMEN) campaign has evolved into a more sophisticated approach as seen in CAPSTONE and NOAA's current campaign, the Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE). The multiyear framework enables partners to leverage shared resources, communicate priorities, and coordinate future fieldwork to avoid duplication of effort.

Under the Explorer Model, collaboration extends beyond the planning phase into mission execution through use of telepresence technology and an open data policy. These two cornerstones of the Explorer Model enable collaboration and make rapid discoveries possible. Using a high-bandwidth satellite connection, remotely operated vehicle (ROV) video; acoustic water

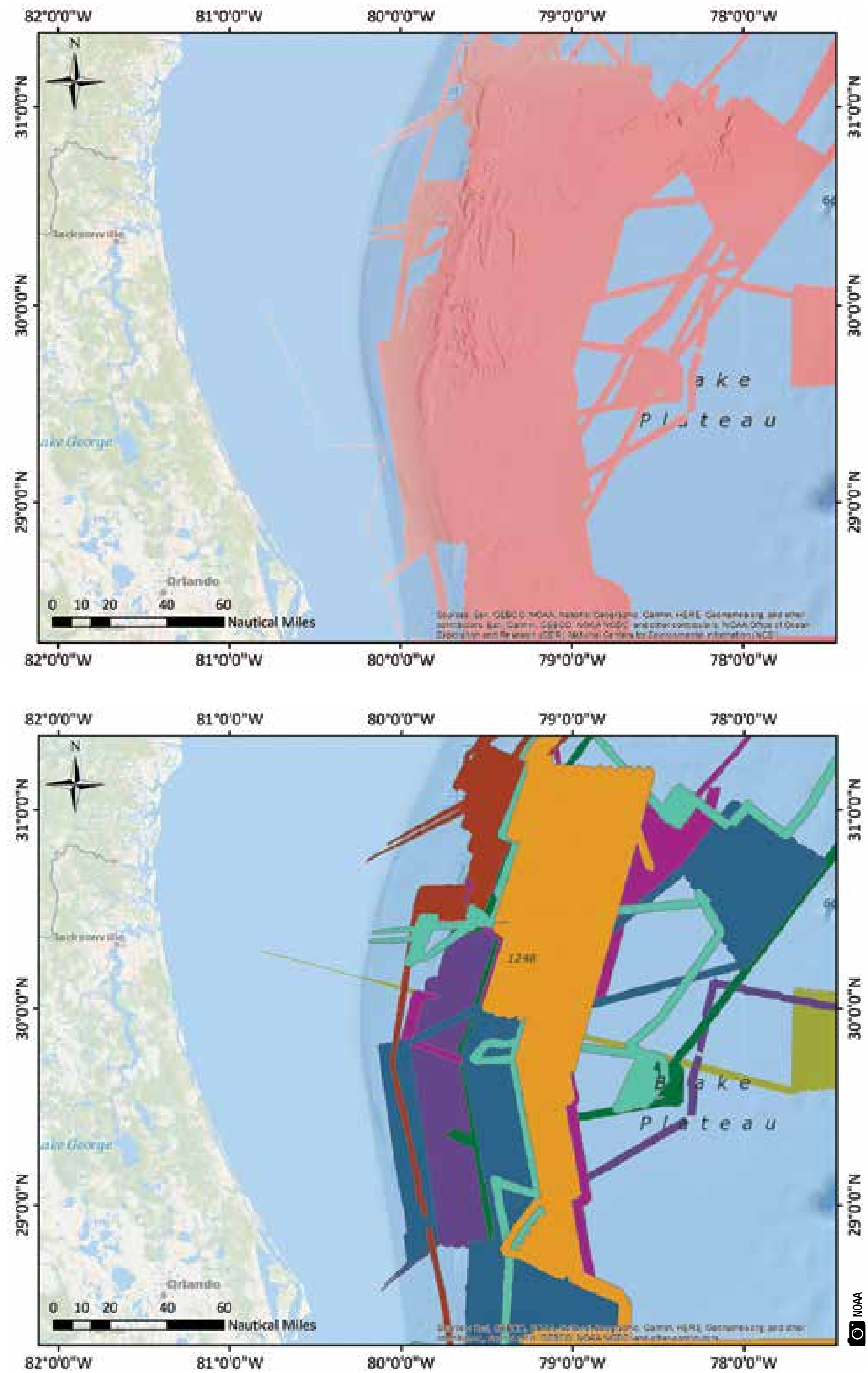

Figure 1: Explorer Model missions build off each other to develop a continuous bathymetric surface. Shown here is the bathymetric coverage collected by the Office of Ocean Exploration and Research on the Blake Plateau (top) and the breakdown of the eight separate cruises (EX1203, EX1403, EX1805, EX1806, EX1903L1, EX1903L2, EX1906, EX1907), which worked together to build mapping coverage (bottom). ROV cruises took advantage of weather days and overnight transits between ROV dives to close data holidays between larger surveys completed by mapping only cruises.

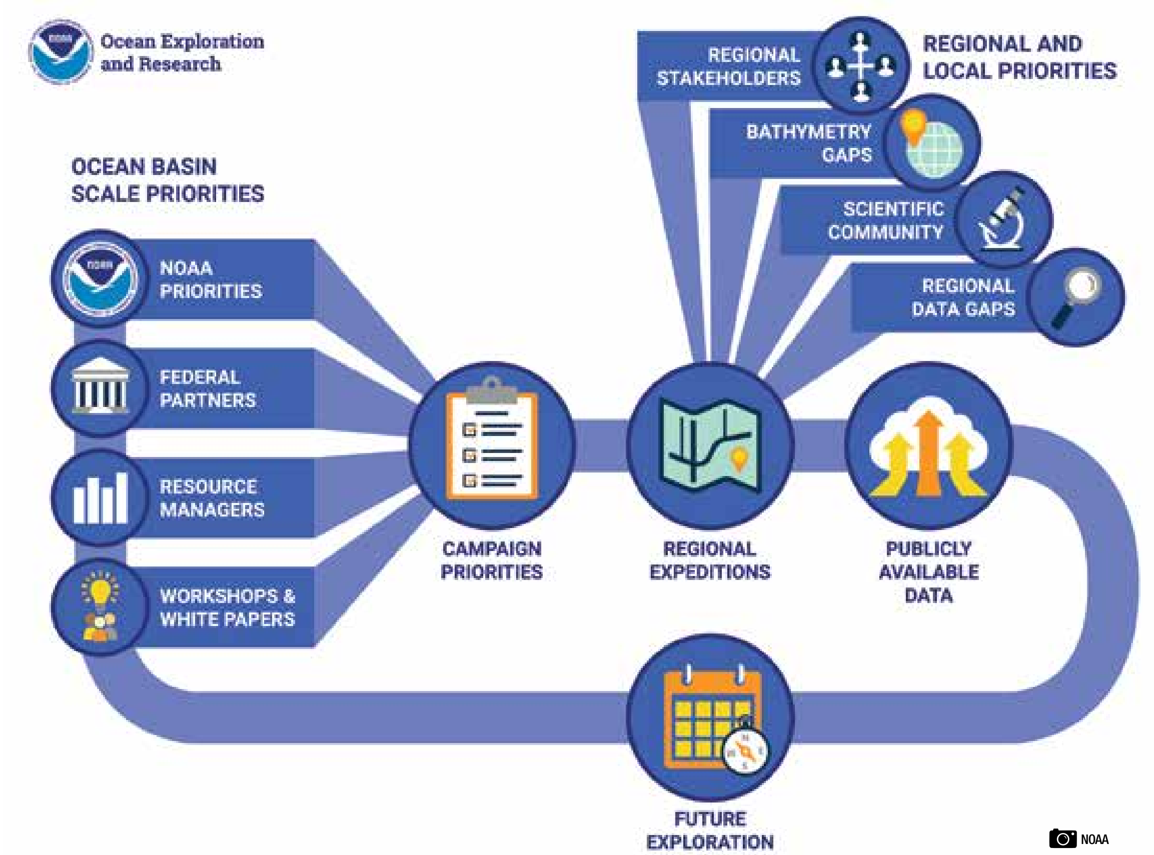

Figure 2: The Explorer Model allows for community input at multiple levels to determine exploration gaps and how best to design expeditions to collect the highest value data. Early on in the planning phases of a campaign, partners, resource managers, and members of the academic, industry, and philanthropic communities are engaged to identify exploration priorities. While campaigns can vary in their scale, scope, and formality, the overarching objectives identified at this level are used to inform expedition plans, with additional input from the science community and regional stakeholders to identify specific targets for exploration. At the conclusion of an expedition, publicly available data and new discoveries feed into the planning cycle for future expeditions and campaigns.

column, seafloor, and sub-seabed data; and oceanographic data are streamed to shore in real time, facilitating both public outreach and engagement with on shore scientists. A suite of Internet-based collaboration tools empowers the shore-based science team to actively participate with the ongoing expedition. Using an instant messaging chat room, scientists are able to discuss observations, participate in operations, and access real-time sensor data. A dedicated File Transfer Protocol brings data to shore in near real time, allowing scientists to immediately begin working with data. Scientific observations are catalogued using the cloud-based annotation system SeaTube, developed by Ocean Networks Canada and used for NOAA ocean exploration expeditions. The combination of the real-time video streams and Internet-based collaboration tools enables researchers anywhere in the world to participate in the expedition, discuss what they are seeing, and guide operations. Telepresence technology makes collaboration possible, but it is the model's focus on the social aspect – the facilitation of ship-to-shore communication and interaction among participating scientists – that makes it successful. Enabling a distributed team of researchers to effectively work together requires an emphasis on participant engagement. If the shore-based scientists feel confused or disenfranchised by what is happening on the ship, it can significantly hamper the success of an expedition. Video streaming is only one component of the framework we use to turn individual shore-based researchers into an integrated team immersed in ongoing operations. Real-time engagement of the team on shore allows for nimble and responsive operational adaptations that direct real-time data acquisition. Daily meetings and a nearly continuous flow of chat messages and e-mails connect the at-sea and shore-based teams to discuss upcoming operations, science objectives, new data, as well as any last minute operational changes. Scientists share recent discoveries, new insights, species identifications, and requests for additional information. Examples of the success of this process are shown in Figure 3.

Beyond consistent person-to-person communication, one critical step to empowering the shore-based science team is to ensure that they have access to data similar to what a scientist would have on the ship. Each component of the Explorer Model is underpinned by open data architecture and collaboration. To enable researchers from around the globe to access expedition data, there is a continuous and automated workflow to upload new data sets to the cloud. Publicly available, open source data has been one of the core principles of the Explorer Model since inception. Data are archived in open source formats, with extensive metadata documentation to meet national and international data principles of findability, accessibility, interoperability, and reusability (FAIR). FAIR data principals embody the OER mission by ensuring data is appropriately managed and that Explorer Model expeditions leave behind a legacy of data to be used by generations to come.

Another key success of the Explorer Model is how the resulting data can be used to inform resource managers responsible for the geographic areas where OER conducts expeditions. OER regularly engages relevant managers and decision makers to understand current and emerging data needs. This involvement allows OER operations

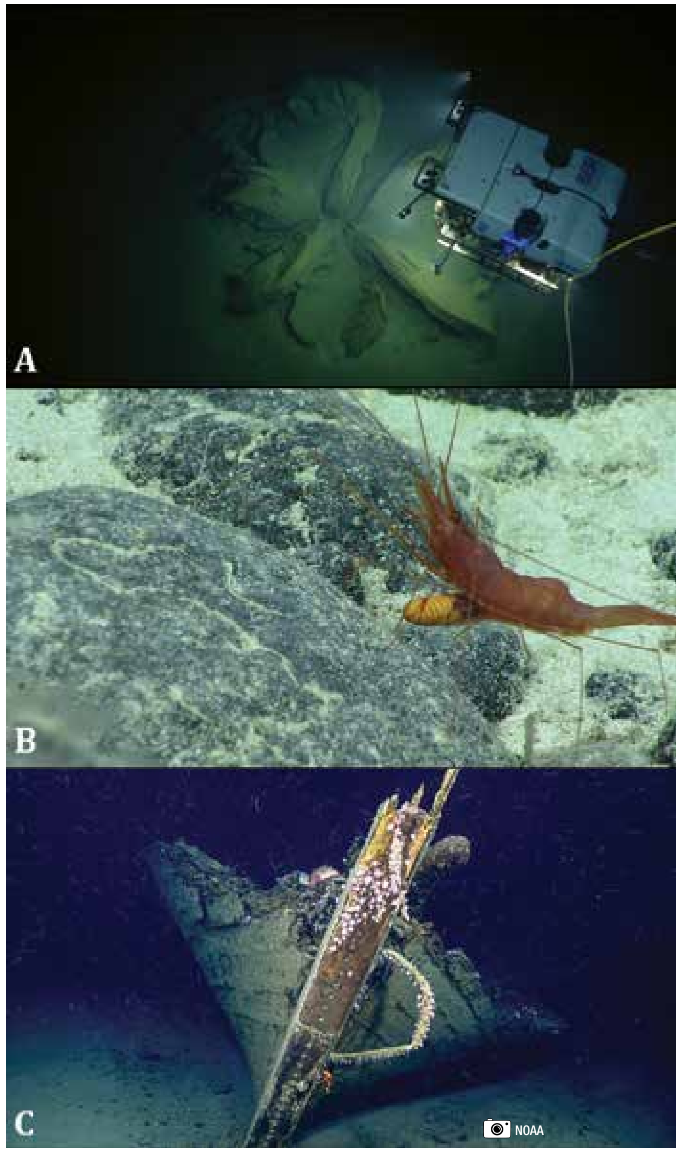

Figure 3: The use of telepresence technologies is an integral part of the Explorer Model. The three images shown here represent three examples of how telepresence was used to facilitate discovery. A) In 2014, while investigating a potential shipwreck target in the Gulf of Mexico, the Office of Ocean Exploration and Research instead found two asphalt extrusions. Once it became clear the feature was geological, the shoreside science complement of the dive was completely converted from archaeologists to geologists in about an hour, providing their expertise and determining how to best use the remaining time in the dive. B) During a dive in the Musicians Seamounts, the at-sea team was stumped by this unusual parasite on a *Nematacarsinus* sp. shrimp. The onboard team reached out to colleagues around the world and within hours they received several responses identifying the parasite as a rhizocephalan barnacle. C) During an engineering shakedown dive in the Gulf of Mexico in 2019, the ROV unexpectedly came upon the wreck of what is likely a mid-19th century wooden sailing vessel. Again, news spread quickly through the routine communication channels OER uses, and a full team of archaeologists were quickly engaged in documenting the shipwreck.

to contribute data that can inform timely management decisions. For example, data from ACUMEN was used to evaluate the ecosystems of the Northeast U.S. submarine canyons and seamounts and improve habitat suitability models in that region. This information helped lead to the establishment of the Frank R. Lautenberg Deep-Sea Coral Protection Area and the Northeast Canyons and Seamounts Marine National Monument. In the Pacific, CAPSTONE data supported the expansion of the Papahānaumokuākea Marine National Monument. Every expedition contributes to our understanding of the deep sea. Discoveries have included previously unknown seafloor features, new species, maritime heritage resources, and unique marine habitats including hydrothermal vent communities, oil and gas seeps, brine pools, and deep-sea coral and sponge communities. Expeditions have also revealed the presence of commercially valuable species and their prey, range extensions, and novel behavioural observations. These data support improved ecosystem models and provide critical information for managers from the local, national, and international level. As we expand the scope and pace of ocean exploration, we must maintain consistent communication and data sharing with decision makers to ensure that they have the information necessary to appropriately manage all newly-discovered habitats and resources.

A Worthwhile Investment

The Explorer Model demonstrates how coordination and collaboration among stakeholders can lead to significant results. While this model is expandable to other platforms and programs, there are a number of challenges and tradeoffs to consider. The Explorer Model requires additional resources in comparison to traditional sea-going research expeditions. A team of dedicated staff are required to enable the Explorer Model and manage coordinated campaigns. However, this coordination is essential to the success of the model and enables participation across different time zones and multidisciplinary science teams. An at-sea staffing constraint is that the sailing team must include a number of engineers and technicians who make real-time communication, video streaming, and data transfers possible. This reduces shipboard science staff which in turn can limit the amount of onboard science operations, such as sample processing. On the *Okeanos Explorer*, there are only two berths for deep-sea scientists who serve as the Science Team Leads, tasked with representing their onshore colleagues. This may not be a limiting factor on all platforms, but certainly something that should be considered during the planning phase of an expedition.

Telepresence-enabled exploration with an open data architecture is not without cost. In addition to increased staffing costs, the high-bandwidth satellite connection necessary to send data to shore in real time adds significant expense to the cost of an expedition. The development and maintenance of a suite of collaboration tools, automated data pipelines, and paired ship and shore infrastructure are other additional, but necessary, expenses. For example, on a traditional research cruise an individual would document observations in a notebook or spreadsheet, both low cost data development solutions. With a distributed science team, we use a cloud-enabled program (SeaTube) for annotations so that participants can engage remotely and instantly share observations. This allows for the generation of a common dataset, optimizing information sharing and the interdisciplinary nature of resulting data. While the upfront expenses are high, they are dwarfed by the efficiencies saved with data processing, sharing, archiving, and the value of the resulting data.

The benefits of empowering a shore-based team, increasing collaboration capabilities, and the educational appeal of sharing discoveries in real time are invaluable. The Explorer Model offers an opportunity to engage a practically limitless science party with a broad array of disciplines. It also provides flexibility to rapidly engage onshore science personnel with pertinent knowledge so a variety of disciplines and experts can respond to unexpected discoveries. OER believes that the added expense and staff burden are worthwhile investments, as Explorer Model expeditions serve as a reconnaissance resource for the entire community, where broad engagement and participation is imperative.

Moving Forward Together

We envision a future with a connected fleet of research platforms and exploration assets across multiple organizations. NOAA OER hopes to foster an inclusive, coordinated network of explorers and operators, leveraging the strengths of each partner to create efficiencies that one group alone cannot achieve. This concept, while not new, will in turn encourage new participants in ocean exploration and enable resource sharing between federal, non-profit, and private sectors. Improved coordination, information dissemination, and new tools are needed to facilitate not only this vision, but also the objectives laid out in the NOMEC strategy and Seabed 2030. As such, NOAA developed the U.S. Bathymetric Gap Analysis – a publicly available resource hosted on NOAA's GeoPlatform to be used by the community to improve awareness of data gaps. OER uses this analysis to identify deep-water mapping gaps and inform exploration campaign planning (Figure 2). NOAA will continue to improve tools available to the community to help assess gaps in other exploration data types (e.g., deep submergence dives, water column data, etc.) and increase the efficiency of expedition planning and opportunistic data gathering.

Over the last decade, new tools have emerged that facilitate broad sharing and collaboration. Low Earth orbit satellites, artificial intelligence, and cloud computing are on the horizon to enable the next era of telepresence-enabled exploration (see *The Future of Telepresence: Low Earth Orbit Communications Satellites, Cloud Computing, and Ocean Exploration* in this issue of the JOT). Soon we will no longer be bandwidth-limited at sea. In the near future, research vessels will likely have similar access to cloud computing and telecommunication infrastructure as labs in major cities. These advancements will only increase the power of collaboration inherent in the Explorer Model and increase processing speed of ocean exploration data.

The telepresence and broad participation components of the Explorer Model offer solutions to many challenges faced by our community by allowing geographically distributed science parties to collaborate as a coordinated team. The nimbleness offered by this approach provides expertise redundancy and expansion, as well as the opportunity to engage personnel not capable of sailing. This helps foster a sense of inclusion in our deep-sea community, and lowers the barrier of entry for early career scientists and underserved communities. Telepresence can also increase our ability to conduct more science on smaller ships. Harnessing the power of the intellectual capital on shore can engage a science team larger than the berthing capacity of any research vessel.

Additionally, as a community we now face new challenges in maintaining operations at sea during a global pandemic. Capitalizing on telepresence technology can allow the continuation of ocean exploration while maintaining the health and safety of all personnel involved. The lessons of the Explorer Model offer a roadmap for how others can incorporate telepresence into their operations in the future to reduce the amount of personnel on board while still facilitating scientific discovery and a connection to the public. The Explorer Model approach to operations offers a resiliency to ocean science, one that we did not previously realize we needed.

Exploration is not only a fundamental part of science, but is also necessary to advance the identification and development of ocean resources, and provide critical information for science-based marine conservation. The Explorer Model demonstrates the value of optimizing collaboration to maximize the utility of expensive ship time. The successes of the Explorer Model serve as a call to arms for the exploration community to work together in order to set the stage for the next era of ocean exploration. The adoption of this model by other entities and the continued emergence of supporting technologies will greatly expand the network of community driven exploration in years to come. Only together, as a connected community of explorers, can we discover what lies beneath the surface of the ocean for the untold benefit to the common good.

Further Reading

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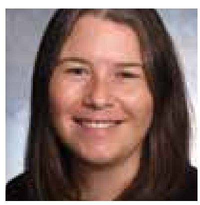
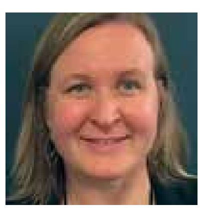
Brian Kennedy is a graduate student in the Rojtan Lab at Boston University working on his PhD in ecology, behaviour, and evolution. His work focuses on deep-sea ecosystems and ocean exploration technologies. Previously, he worked with NOAA Office of Exploration and Research as a deputy program manager, expedition manager, and telepresence coordinator.

Dr. Mashkoor Malik is a Physical Scientist (Hydrographer) with NOAA Office of Ocean Exploration and Research. He received his MS in ocean mapping and IHO Category A certification in 2005 and PhD in 2019 from the University of New Hampshire, CCOM/JHC. His primary research interests include seafloor mapping and habitat characterization.



Kelley Suhre is the Deputy Chief of the Explorations and Expeditions Division of NOAA's Office of Ocean Exploration and Research. She has more than a decade of experience coordinating and managing ocean exploration projects and expeditions around the globe, including serving as the Senior Expedition Manager for NOAA Ship *Okeanos Explorer* (EX). She is an expert in community-driven and telepresence-enabled ocean exploration, and has conducted 13 successful EX expeditions, including 10 with the majority of the science team participating remotely via telepresence. She has a bachelor's in conservation studies from New Century College at George Mason University, and a master's in maritime archaeology from the University of Southampton.



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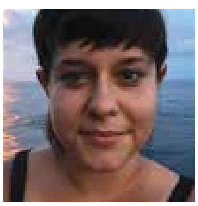

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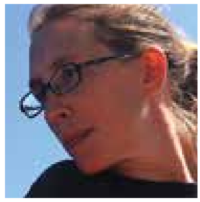

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