Strategic Priorities for Ocean Exploration and Characterization of the United States Exclusive Economic Zone

Prepared by the

Interagency Working Group on Ocean Exploration and Characterization

for the

National Ocean Mapping, Exploration, and Characterization Council *and*

Ocean Science and Technology Subcommittee *of the*

Ocean Policy Committee

October 2022

About the Ocean Policy Committee

The Ocean Policy Committee (OPC) was codified in the National Defense Authorization Act for Fiscal Year 2021 to coordinate federal actions on ocean-related matters and is co-chaired by the Director of the Office of Science and Technology Policy (OSTP) and the Chair of the Council on Environmental Quality (CEQ). The OPC is directed to engage and collaborate with the ocean community on ocean-related matters, identify priority ocean science and technology needs, and to leverage resources and expertise to maximize the effectiveness of federal investments in ocean research. For more information about the work of the OPC, please see noaa.gov/interagency-ocean-policy.

About the Ocean Science and Technology Subcommittee

The purpose of the Ocean Science and Technology (OST) Subcommittee under the OPC is to advise and assist on national issues of ocean science and technology. The OST contributes to the goals for federal ocean science and technology, including developing coordinated interagency strategies and fostering national ocean science and technology priorities.

About the National Ocean Mapping, Exploration, and Characterization Council

The OPC established the National Ocean Mapping, Exploration, and Characterization (NOMEC) Council in June 2020 pursuant to the "National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone," which was developed per Section 2 of the November 2019 Presidential Memorandum on Ocean Mapping of the United States Exclusive Economic Zone and the Shoreline and Nearshore of Alaska. The purpose of the NOMEC Council is to coordinate Federal agency policy and actions needed to advance ocean mapping, exploration, and characterization, and to support collaboration with both non-Federal and nongovernmental partners and stakeholders. The NOMEC Council develops and implements multi-disciplinary, collaborative, and coordinated approaches to mapping, exploring, and characterizing the Exclusive Economic Zone of the United States (United States EEZ). The NOMEC Council reports to the OPC's OST Subcommittee, which provides support and guidance for the NOMEC Council's work as appropriate. The OPC provides strategic direction and facilitates interagency resolution of policy issues as appropriate.

About the Interagency Working Group on Ocean Exploration and Characterization

The Interagency Working Group on Ocean Exploration and Characterization (IWG-OEC), created in September 2020, is charged with helping to implement the 2019 Presidential Memorandum on Ocean Mapping, particularly Section 2's "National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone" (NOMEC Strategy). The NOMEC Council provides direction and support to the IWG-OEC and consults and relies on the technical expertise and operational capacities of IWG-OEC members/agencies in implementing its objectives. The IWG-OEC recommends and facilitates exploration and characterization efforts that provide needed information and insights about deep-water (>40 meters (m)) environments of the United States EEZ, including the seafloor, sub-bottom, and water column, from exploratory initial assessments to comprehensive characterization in direct support of specific research, resource management/stewardship, policymaking, or applied mission objectives, as well as integrated ocean science.

About the Interagency Working Group on Ocean and Coastal Mapping

The Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM) is a working group of the National Science and Technology Council Subcommittee on Ocean Science and Technology (SOST), and also reports to the OST Subcommittee of the OPC via the NOMEC Council. The SOST serves as the lead interagency entity for Federal coordination on ocean science and technology. The IWG-OCM was established in 2006 to "facilitate the coordination of ocean and coastal mapping activities and avoid duplicating mapping activities across the Federal sector as well as with State, private sector, academic, and non-governmental mapping interests" (National Ocean and Coastal Mapping Strategic Action Plan 2009). The IWG-OCM focus areas, which includes United States coasts, Great Lakes and oceans out to the limits of the United States EEZ, and our extended continental shelf, were established by the Ocean and Coastal Mapping Integration Act of 2009. The IWG-OCM also represents the ocean and coastal mapping aspects of elevation on the Federal Geographic Data Committee's 3D Nation Elevation Subcommittee.

About this Document

This report on Strategic Priorities for Ocean Exploration and Characterization in the United States Exclusive Economic Zone fulfills Objective 3.1 of the NOMEC Implementation Plan, prepared by the NOMEC Council in January 2021. This document identifies key strategic priorities for ocean exploration and characterization, addressing the NOMEC Strategy's charge to identify, explore, and characterize "priority areas" as directed in the 2019 Presidential Memorandum.

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Abbreviations and Acronyms

AOA	Aquaculture Opportunity Area
AUV	Autonomous Underwater Vehicle
BOEM	Bureau of Ocean Energy Management
CEQ	Council on Environmental Quality
COL	Consortium for Ocean Leadership
eDNA	Environmental DNA
EEZ	Exclusive Economic Zone
FDA	Food and Drug Administration
GOM	Gulf of Mexico
IWG-OCM	Interagency Working Group on Ocean and Coastal Mapping
IWG-OEC	Interagency Working Group on Ocean Exploration and Characterization
NOAA	National Oceanic and Atmospheric Administration
NOMEC	National Ocean Mapping, Exploration, and Characterization
NSF	National Science Foundation
OEC	Ocean Exploration and Characterization
OER	Office of Ocean Exploration and Research
ONR	Office of Naval Research
OPC	Ocean Policy Committee
OST	Ocean Science and Technology subcommittee
OSTP	Office of Science and Technology Policy
ROV	Remotely Operated Vehicle
SOST	Subcommittee on Ocean Science and Technology
UCH	Underwater Cultural Heritage
USGS	United States Geological Survey

Executive Summary

Understanding the global ocean is vital to secure a healthy, safe, and prosperous future, and yet the ocean remains the planet's greatest unknown habitat, a vast expanse of "inner space." Currently, only 48 percent of the seafloor within the United States Exclusive Economic Zone (U.S. EEZ) has been minimally mapped and only a fraction of that has been adequately explored or characterized for specific purposes. Exploration and characterization data can inform ocean-based solutions to ongoing challenges (including climate change and biodiversity loss), promote ecosystem management and conservation, and support a sustainable ocean economy.

To facilitate ocean exploration and characterization, the National Ocean Mapping, Exploration, and Characterization (NOMEC) Council tasked the Interagency Working Group for Ocean Exploration and Characterization (IWG-OEC) with identifying and synthesizing thematic and geographic priorities for ocean exploration and characterization (OEC). To fulfill this charge, the IWG-OEC assembled subgroups of subject matter experts from Federal agencies into five thematic areas: benthic ecology, cultural heritage, marine resources, seafloor hazards, and the water column. These groups submitted white papers (see Appendix A) detailing thematic and geographic priorities for OEC along with relevant data needs and challenges, which are briefly summarized in this document.

Several geographic priority areas were identified by multiple subgroups, including the Aleutian Arc (all five subgroups), the U.S. Caribbean (four subgroups), the California Coastal Region (four subgroups), and the Pacific Islands (three subgroups). Likewise, groups largely converged upon several thematic priorities, including targeted sampling (all five subgroups), fundamental biogeochemistry and water characteristics (four subgroups), Autonomous Underwater Vehicle/Remotely Operated Vehicle (AUV/ROV) mapping (four subgroups), multibeam mapping (four subgroups), and backscatter measurements (four subgroups). Public input was also solicited using both listening sessions and formal Federal Register notices to identify priority areas for OEC. Three emerging priorities for exploration and characterization have more recently been considered and added here: climate change, biodiversity, and environmental justice. Exploration and characterization can provide useful data for managers, decision makers, and stakeholders to make informed science-based decisions, and in ways that are equitable to all Americans, in areas that currently lack data.

This report complements an ongoing effort by the Interagency Working Group on Ocean and Coastal Mapping to solicit and compile the spatial priorities of Federal agencies that conduct and rely on ocean and coastal mapping activities. Together, these two interagency working groups' efforts represent the first time the Federal government has collectively identified ocean mapping, exploration, and characterization priorities for the entire U.S. EEZ.

Because of the immense extent of the U.S. EEZ, both prioritization and multi-sectoral collaboration and participation are needed to meaningfully advance these priorities. This report

serves as a living document that will be updated periodically to reflect progress and changing stakeholder needs.

Introduction

The 2019 Presidential Memorandum on Ocean Mapping of the United States Exclusive Economic Zone and the Shoreline and Nearshore of Alaska required the creation of the National Strategy for Mapping, Exploring, and Characterizing the U.S. EEZ ("NOMEC Strategy"),[1] finalized in June 2020. The NOMEC Strategy outlines a phased approach to map the seafloor of the entire U.S. EEZ, identify specific geographic and thematic priority areas, and explore and characterize these priority areas. The U.S. EEZ extends up to 200 nautical miles from shore and covers more seafloor area than all 50 states combined, but to date only 48 percent of it has been minimally mapped[2] (at least 1 sounding in a 100-meter cell) and only a fraction of that has been explored or characterized. The Strategy, therefore, emphasizes the need for innovation and leveraging the expertise and resources of multi-sectoral partnerships. The NOMEC Strategy's Implementation Plan,[3] released in January 2021, details specific objectives and milestones needed to achieve the Strategy's goals.

Mapping, exploring, and characterizing our waters provides the fundamental knowledge necessary to conserve, use, and sustain our ocean. Exploration and characterization data are critical to informing conservation and management of healthy ocean ecosystems, particularly in the vast swaths of the U.S EEZ for which little is known about the seafloor, the water column, and the ecosystems that connect them. Deep ocean environments act as heat and carbon sinks, and harbor substantial but poorly understood biodiversity. The NOMEC Strategy and its Implementation Plan will help advance scientific understanding, contribute to the Nation's economic prosperity, promote the health and security of all Americans, and provide data needed to maintain healthy, productive, and resilient ocean ecosystems (including the provision of important ecosystem services). Better understanding of past, current, and future ocean conditions can inform ocean-based solutions to a variety of ongoing challenges, including climate change and biodiversity loss. To improve our understanding of the U.S. EEZ, the NOMEC Strategy outlines five goals for action: (1) coordinate interagency efforts and resources to map, explore, and characterize the U.S. EEZ; (2) map the U.S. EEZ; (3) explore and characterize priority areas of the U.S. EEZ; (4) develop and mature new and emerging science and technologies to map, explore, and characterize the U.S. EEZ; and (5) build public and private partnerships to map,

[1] Ocean Science and Technology Subcommittee (2020) National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone. https://www.noaa.gov/sites/default/files/2021-08/NOMEC%20Strategy.pdf

[2] Interagency Working Group on Ocean and Coastal Mapping (2022) Progress Report: Unmapped U.S. Waters. https://iocm.noaa.gov/documents/mapping-progress-report2022.pdf

[3] National Ocean Mapping, Exploration, and Characterization Council (2021) Implementation Plan for the National Strategy for Ocean Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone. https://www.noaa.gov/sites/default/files/2021-11/210107-FINALNOMECImplementationPlan-Clean.pdf

explore, and characterize the U.S. EEZ. Within the NOMEC Strategy, the terms mapping, exploration, and characterization are defined as:

- **Mapping:** Ocean mapping provides comprehensive data and information needed to understand seafloor characteristics such as depth, topography, bottom type, sediment composition and distribution, and underlying geologic structure.
- **Exploration**: Ocean exploration provides a multidisciplinary first look at an unknown or poorly understood area of the seafloor, sub-bottom, and/or water column and an initial assessment of an area's physical, geological, chemical, and biological characteristics.
- **Characterization:** Ocean characterization provides comprehensive data and interpretations for a specific area of interest of the seafloor, sub-bottom, and/or water column, in direct support of specific research, resource management, policymaking, or applied mission objectives.

The Interagency Working Group on Ocean Exploration and Characterization (IWG-OEC) was established in August 2020 as a result of the NOMEC Strategy's development. It includes members from the Bureau of Ocean Energy Management (BOEM), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), U.S. Navy, Department of Energy, Office of the Director of National Intelligence, U.S. Food and Drug Administration (FDA), National Aeronautics and Space Administration, National Science Foundation (NSF), Office of Management and Budget, Office of the Secretary of Defense, and Office of Science and Technology Policy (OSTP). The IWG-OEC is charged with assisting the NOMEC Council to implement the NOMEC Strategy and Implementation Plan. The NOMEC Council provides high-level direction and support to the IWG-OEC and in turn relies on the technical expertise and operational capabilities of IWG-OEC members/agencies. The IWG-OEC recommends and collaboratively facilitates exploration and characterization efforts that provide information and insights about deep-water (>40 m) environments (including the seafloor, sub-bottom, and water column) from initial exploratory assessments to more comprehensive characterization that supports specific research, resource management/stewardship, policymaking, or applied mission objectives. For example, to address legislative requirements of the National Environmental Policy Act, agencies must provide detailed descriptions of the physical and biological environment in areas that could potentially be impacted by human activities. As shipping, offshore renewable energy development, aquaculture siting, and other uses are considered within our ocean, collection of basic exploration and characterization data of relevant marine habitats will be critical to fulfilling such regulatory requirements, informing decision making on conflicting uses of the ocean, and evaluating and monitoring the impacts of these activities.

As its first major deliverable to the NOMEC Strategy, the IWG-OEC has produced this report, Strategic Priorities for Ocean Exploration and Characterization in the United States Exclusive Economic Zone, which fulfills Objective 3.1 of the NOMEC Implementation Plan:

> *Identify key strategic priorities for ocean exploration and characterization to address the President's direction to identify, explore, and characterize "priority areas" within the United States EEZ. Executing this goal will require the consideration of multiple factors, including statutory requirements, federal agency missions, strategic national issues, Administration policy priorities, and stakeholder perspectives. Specific geographic and thematic priorities will be identified through workshops, requests for information, and other avenues to solicit input from a multitude of partners and stakeholders.*

To fulfill this charge, the IWG-OEC followed an approach similar to that of the "Workshop to Identify National Ocean Exploration Priorities in the Pacific",[4] which convened subject matter breakout groups to identify exploration priorities in the Pacific basin. The IWG-OEC assembled 92 subject matter experts from 14 Federal agencies to provide input across advisory groups (hereinafter "subgroups") covering five thematic areas: benthic ecology, seafloor hazards, the water column, cultural heritage, and marine resources. These subgroups each completed their own prioritization process and produced detailed white papers outlining their top thematic and geographic priorities (along with other areas that were considered, see Appendix A). Additionally, public input was sought throughout the drafting process through Federal Register notices and through public listening sessions.

What follows in this report is a synthesis of the identified priorities. Each subgroup implemented its own unique process to provide discipline-specific recommendations, although many of the identified priorities overlap both thematically and geographically. In concert with Administration guidance via the Ocean Policy Committee (OPC), the Ocean Science and Technology subcommittee (OST), and relevant Presidential Executive Actions, this report's recommendations can inform how Federal agencies direct limited resources for ocean exploration and characterization while fulfilling agency-specific missions. Because true prioritization required the subgroups to limit the number and spatial extent of recommendations, this initial report could not incorporate or fully detail all of the considered priorities or interests.

[4] Fillingham K, Rogers D, Yarincik K (2020) Report on the Workshop to Identify National Ocean Exploration Priorities in the Pacific. Consortium for Ocean Leadership. https://oceanleadership.org/wp-content/uploads/2020/11/OceanExploration_PacificPriorities_WorkshopReport_NOV2020.pdf

The strategic recommendations and priorities summarized here provide an initial framework to inform and guide ocean exploration and characterization (OEC) efforts in the U.S. EEZ. Given the iterative and open-ended nature of such endeavors, which often yield more questions than answers, it is expected that this framework will continue to evolve, adapt, and improve over time as new scientific information comes to light and as the nation's strategic needs and priorities shift. Therefore, this priorities report will be revisited and updated at regular intervals and should be considered a living document. The following priority recommendations have not been prioritized relative to each other and are not intended to be overly prescriptive or static. Sustained, ongoing public engagement is encouraged by the Council and IWG-OEC through participation in scientific conferences, public workshops and forums, and similar venues. Exploration and characterization priorities will also be informed by the latest guidance of the NOMEC Council, OST, and OPC, and relevant Presidential Executive Actions.

Complementary Efforts

While this report represents the first time that the Federal government has collectively identified ocean exploration and characterization priorities for the entire U.S. EEZ, similar and complementary efforts have been completed before[5,6] or are currently underway. Two such efforts that will also inform and guide national exploration and characterization are briefly summarized below.

IWG-OCM Spatial Priorities Study

Mapping is an important prerequisite for most ocean exploration and characterization activities, which therefore benefit from working in parallel with mapping-focused activities. In 2020, the Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM) began one such activity with its Spatial Prioritization Study of the U.S. EEZ,[7] which aims to comprehensively gather the mapping priorities of Federal agencies that conduct and rely on ocean and coastal mapping activities. This study asks IWG-OCM agencies to define geographic areas of the U.S. ocean, coasts, and Great Lakes where mapping data are needed, and why. The study will allow IWG-OCM partners to identify overlaps in mapping requirements so that resources can be allocated efficiently. Other goals include enhancing participants' ability to coordinate and leverage

[5] NOAA Ocean Exploration (2018) Summary Report for the Atlantic Seafloor Partnership for Integrated Research and Exploration Science Planning Workshop. https://oceanexplorer.noaa.gov/explorations/aspire/aspire-workshop-report.pdf

[6] Netburn AN (2018) From Surface to Seafloor: Exploration of the Water Column (Workshop Report). NOAA Ocean Exploration. https://doi.org/10.25923/rnjx-vn79

[7] Initial results for NOAA can be found on the U.S. Mapping Coordination SeaSketch site: https://www.seasketch.org/#projecthomepage/5272840f6ec5f42d210016e4/about

resources with other agencies that have shared mapping needs. IWG-OCM's work will highlight the geographic mapping needs in the U.S. EEZ at a broad level, while this exploration and characterization priorities report includes a more detailed narrative description of both thematic and geographic priorities, as identified by numerous Federal agencies, and thus provides an additional level of granularity for more targeted exploration and characterization studies.

Workshop to Identify National Ocean Exploration Priorities in the Pacific

In partnership with NOAA's Office of Ocean Exploration and Research (NOAA OER), the Consortium for Ocean Leadership (COL) hosted the "Workshop to Identify National Ocean Exploration Priorities in the Pacific" as a series of virtual meetings in 2020, with participants representing 46 organizations (Federal agencies, academic institutions, industry, philanthropy, and private sector). The workshop was organized to help NOAA OER and its partners plan future exploration efforts in the Pacific. Prior to the start of the workshop, COL solicited white papers from the community to help define geographic and thematic priorities in the region; a very similar white paper template was employed for this IWG-OEC report. The workshop was structured to include a series of breakout discussions centered on five subject areas: seafloor characterization, biology characterization, marine resources, water column characterization, and cultural heritage. Many of the resulting priorities identified through the COL workshop[8] are also identified in this report.

IWG-OEC Priorities Development

Based on the successful process framework used for the COL Pacific Priorities Workshop report,[9] the IWG-OEC formed subject area subgroups to identify strategic OEC priorities in the U.S. EEZ, per Goal 3.1 of the NOMEC Strategy. Experts identified the following five disciplines with known strategic relevance and clear needs for coordinated ocean exploration and characterization: benthic ecology, seafloor hazards, water column, cultural heritage, and marine resources. IWG-OEC member agencies identified well-qualified subject matter experts within their agencies who could participate in subject area advisory groups for those disciplines. Ninety-two subject matter experts participated from 15 Federal agencies. Subgroup size ranged from 10 to 29 participants.

The IWG-OEC co-chairs charged all subgroups with identifying their highest thematic and geographic priorities for their subject area and then providing responses to the IWG-OEC using a standard white paper template (Appendix B). The two largest subgroups, benthic ecology and

[8] Fillingham K, Rogers D, Yarincik K (2020) Report on the Workshop to Identify National Ocean Exploration Priorities in the Pacific. Consortium for Ocean Leadership. https://oceanleadership.org/wp-content/uploads/2020/11/OceanExploration_PacificPriorities_WorkshopReport_NOV2020.pdf

[9] ibid.

marine resources, chose to break into smaller teams based on thematic or geographic subsets. More details on the subgroups' processes can be found in their white paper submissions (Appendix A). All subgroups had access to a GIS web map where they could create, edit, and share priorities among subgroup members with user-friendly geospatial tools.

Each subgroup interpreted the charge slightly differently and provided unique feedback through its final white paper. Two groups fully prioritized geographic areas of interest and provided shapefiles; one group provided unranked geospatial priority shapefiles; and two groups provided unranked geographic areas of interest without shapefiles. All provided thematic priorities, with varying levels of detail, along with discussion of data needs, potential partners, technologies, and challenges. IWG-OEC co-chairs then compiled the input into this report, but did not further prioritize the input.

Public Input to Date and Continuing Engagement

Though the primary method for identifying strategic priorities was limited to Federal agency representatives, public input about OEC priorities has been sought throughout the larger process being led by the NOMEC Council and via comments on a draft version of this report. Public comment was first solicited through a Federal Register notice[10] in October 2020. This solicitation requested the public to provide geographic and thematic priorities for exploration and characterization as well as identify key data variables, tools, and technologies needed. A second Federal Register notice[11] requested public comment on a draft that was released in March 2022. Respondents to the Federal Register notices represented individuals and communities from academia, industry, philanthropy, state government, and non-governmental organizations. In addition to the geographic, thematic, and data priorities highlighted throughout this report, respondents noted interest in improving collaborations among Federal government and regional and industry partners to leverage existing capabilities in OEC (see Appendices C and D for responses).

The NOMEC Council has so far held three listening sessions to solicit input on aspects of the Strategy and its Implementation Plan: two for a general stakeholder audience in November 2020,

[10] NOAA Office of Oceanic and Atmospheric Research (2020) Request for Information; Implementation Plan for the National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone. Federal Register 85, 64448. https://www.federalregister.gov/documents/2020/10/13/2020-22413/request-for-information-implementation-plan-for-the-national-strategy-for-mapping-exploring-and

[11] NOAA Office of Oceanic and Atmospheric Research (2022) Public Comment of the Office of Ocean Exploration and Research. Federal Register 87, 16169. https://www.federalregister.gov/documents/2022/03/22/2022-05955/public-comment-of-the-office-of-ocean-exploration-and-research

and a third focused on a Tribal audience in January 2021. In these sessions, the NOMEC Council asked the stakeholders and Tribal representatives for their thoughts on how NOMEC should continue to engage with non-Federal stakeholders. Participants in all three sessions emphasized a desire for transparent and accessible data storage for public use with strong metadata standards. Tribal representatives highlighted the importance of ethical data governance aligned to the FAIR-CARE (Findable Accessible Interoperable Reusable - Collective benefit Authority to control Responsibility Ethics) principles.[12] As with the written responses to the Federal Register notices, the listening sessions' participants emphasized the importance of regional and national cooperation across sectors and with Tribal governments to promote equitable representation and involvement in shared mapping, exploration, and characterization efforts.

Thematic Priorities

Benthic Ecology

Thematic priorities (shown in italic blue font) identified by the Benthic Ecology subgroup include a variety of ***sensitive benthic ecosystems***. The complex, biogenic structural habitats created by certain deep-sea (i.e., cold-water) corals and sponges can significantly boost local seafloor and water column biodiversity, but face threats from physical disturbance and changing water chemistry (e.g., climate change-driven acidification and deoxygenation). Specifically identified thematic priorities for benthic ecology include exploration and characterization of ***deep-sea corals and sponges***,[13] ***essential fish habitats and bycatch***, and unique species associated with ***chemosynthetic environments***, including cold seep and hydrothermal vent communities.

Cultural Heritage

Maritime heritage includes shipwrecks, archaeological sites, archival documents, and intangible heritage of ancient and modern peoples who have lived on and along the ocean. The Cultural Heritage subgroup identified three thematic priorities. ***Paleocultural landscapes*** lie on the outer continental shelf and were above water during the last glacial period. These areas may contain evidence of early human migrations as well as exploitation and occupation of now-submerged landscapes. Many of these areas correspond with oral histories of Tribal Nations and may have important meaning to those Tribes today. Another identified thematic priority is ***threats related to underwater cultural heritage (UCH).*** Threats to UCH include climate change-associated impacts, natural disasters, and anthropogenic activities. UCH can be a threat itself and present

[12] *See* Carroll SR, Herczog E, Hudson M, Russell K, Stall S (2021) Operationalizing the CARE and FAIR Principles for Indigenous data futures. Scientific Data 8, 108. https://doi.org/10.1038/s41597-021-00892-0

[13] NOAA Coral Reef Conservation Program (2010) NOAA Strategic Plan for Deep-Sea Coral and Sponge Ecosystems: Research, Management, and International Cooperation. https://www.coris.noaa.gov/activities/deepsea_coral/dsc_strategicplan.pdf

an environmental hazard such as a polluting shipwreck, or by presenting navigational hazards. The final thematic priority is ***ecological contributions of UCH***, as the hard substrates of shipwrecks can provide complex reef-like habitats and serve as biodiversity hotspots.

Marine Resources

The Marine Resources subgroup had a broad scope. Hydrocarbons – oil, gas, and gas hydrates – were initially considered but were ultimately excluded from this prioritization exercise based on NOMEC Council guidance that NOMEC's primary focus is on seafloor and water column-related exploration and characterization rather than the subsurface, and because of the unique reliance on deep-penetrating technologies to characterize subsurface hydrocarbon resources. The subgroup identified six thematic priorities: fisheries habitat, aquaculture, renewable energy, critical minerals, deep (>40m) sand and gravel, and natural products. ***Fisheries habitats*** are of economic and national security interest, as well-managed domestic fisheries can reduce dependence on imported marine food products. They represent a nexus of stakeholder and management interests, including conservation, recreation, and Indigenous use. ***Aquaculture*** includes the cultivation of diverse marine foods using a variety of methods. Improved mapping, exploration, and characterization data—especially of the water column—are needed to inform aquaculture development. There is significant potential for ***renewable energy*** with growing interest in offshore wind and marine energy (wave, tidal, current, and thermal gradients).[14] Exploration and characterization data related to benthic communities, seafloor geology, sediments, and geohazards can help guide siting of potential leasing and development. ***Critical minerals*** in the U.S. EEZ include deep offshore deposits to coastal marine minerals of terrestrial origin. These marine minerals are of commercial and national security interest, including for renewable energy applications. Exploration and characterization data are needed to identify and assess marine critical minerals as well as provide baseline information on associated ecosystems. ***Deep sand and gravel*** are important offshore sediment resources for coastal communities and industries, especially renourishment projects; climate change is predicted to further increase demand for these limited resources. Adequate resource identification and quantification requires a variety of characterization methods. Finally, the exploration and identification of marine ***natural products*** is important for a variety of potential business sectors: pharmaceutical, cosmetic, manufacturing, industrial, agricultural, etc. Discovery of novel marine natural products is connected to our understanding (exploration and characterization) of biodiversity (especially invertebrates and microbes) and thus management and conservation thereof.

[14] LiVecchi A, Copping A, Jenne D, Gorton A, Preus R, Gill G, Robichaud R, Green R, Geerlofs S, Gore S, Hume D, McShane W, Schmaus C, Spence H (2019) Powering the Blue Economy; Exploring Opportunities for Marine Renewable Energy in Maritime Markets. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. https://www.energy.gov/sites/prod/files/2019/03/f61/73355.pdf

Seafloor Hazards

The Seafloor Hazards subgroup identified three thematic priorities with significant knowledge gaps. Subduction zones and offshore crustal faults produce some of the world's largest ***earthquakes*** and trans-oceanic tsunamis. ***Submarine landslides*** are capable of generating tsunamis and impacting vital seafloor, coastal, and terrestrial infrastructure. Finally, the subgroup recommends targeted studies of ***submarine volcanic eruptions*** to further understand their eruptive history and hazard potential.

Water Column

The Water Column subgroup identified three broad thematic priorities. One is ***biological characterization of pelagic ecosystems*** across trophic levels and depths with an emphasis on basic ecosystem structure, applications, and benthic-pelagic coupling. Another identified need is for ***improved characterization of fundamental biogeochemical and physical oceanographic properties*** (e.g., acoustic characteristics, light levels, turbidity, primary productivity, elemental stocks, temperature, salinity, current profiles), including properties important to transportation of dissolved and suspended materials. Finally, the group recommended ***improved characterization of oceanographic features, trends, and events*** such as methane plumes, hypoxic regions, and acidification.

Public Input for Thematic Priorities

Through public comments, stakeholders identified several broad thematic priorities largely aligned to developing a sustainable blue economy and habitat conservation. Critical minerals were highlighted, including the need to understand baseline biodiversity and ecosystem functioning and how these may be impacted by exploratory or extractive activities. One respondent noted that some hydrocarbons naturally seep up through faults in the seabed, are commonly associated with benthic chemosynthetic communities, and can be characterized using certain survey techniques. Another respondent noted the importance of the marine environment in identifying petroleum replacement technologies for consumer products beyond the energy industry (e.g., plastics and food additives). One comment recommended prioritization of historical ocean dump sites of industrial, hazardous, and military waste. The commenter suggested using newly developed technologies and methods to explore and characterize the scope and condition of such sites and to better understand potential environmental and human health impacts. Public input identified deep-sea fisheries habitats and development of new areas for permitting aquaculture operations, which could help address food insecurity. Industry respondents suggested a focused effort on regions in which industry already operates in order to maximize use of existing survey assets. The need for better baseline mapping was also highlighted

as a key thematic priority, including areas that have been previously mapped but to insufficient resolution for various mission needs.

Geographic Priorities

Benthic Ecology

The Benthic Ecology subgroup identified the following geographic priorities *in ranked order*:

1. ***Aleutian Islands and Slope*****:** Based on the limited mapping and exploration that has occurred around the Aleutian Islands, this region hosts some of the densest and most diverse deep-sea coral and sponge assemblages in the U.S. EEZ. These habitats support rich communities of invertebrates and fishes, including commercial species, and have the nation's highest fisheries bycatch of vulnerable corals and sponges. There is a high potential for further scientific discoveries. The Federal waters off Alaska (specifically off of the Aleutian Islands and in the Gulf of Alaska) also offer opportunities for marine aquaculture. All of these require some degree of seafloor mapping data acquisition prior to visual observations and sample collections.
2. ***Southeast U.S. Blake Plateau and "Million Mounds"*****:** This priority area consists of five interconnected regions of the Central and Western Blake Plateau off the Southeastern U.S. Atlantic coast. The Central and Southern Blake Plateau in depths of 350-900 m are not fully mapped but may contain some of the largest aggregations of deep-sea coral reefs/mounds in the world. These deep-sea coral reefs may have significant importance for understanding regional biogeochemical cycling, connectivity of deep-sea species, and—due to their extreme temperature variability—how future ocean change will impact deep-sea coral reefs.
3. ***Mesophotic and Deep Habitats throughout the U.S. Caribbean EEZ*****:** This priority covers the Caribbean EEZ, including Mona Passage, which connects the Atlantic Ocean to the Caribbean Sea off Puerto Rico, North and South of Puerto Rico, and waters surrounding the U.S. Virgin Islands (St. Thomas, St. John, and St. Croix). This region harbors coral gardens, submarine canyons, mesophotic reefs, iron-manganese nodules, and trenches. Caribbean shallow-water reefs are relatively well characterized, but reefs in mesophotic (~40-150 m) and rariphotic (~130-300 m) depth zones remain poorly known. The proximity of very deep waters to land and the expansion of offshore fishing into these deeper habitats present potential threats that make them a priority for characterization of benthic habitat/essential fish habitat. The proximity to shore also provides an opportunity to characterize unique habitats connected across depth zones. The Puerto Rico Trench, where the Caribbean plate collides with the North American plate, warrants further exploration.

4. ***Cascadia Margin and Gorda Ridge Area:*** In the Pacific Northwest, the Cascadia Margin and Gorda Ridge are of particular interest for a number of reasons. Gorda Ridge is the only mid-ocean spreading center in the U.S. EEZ. The Cascadia Margin stores a high volume of methane; baseline characterization of methane seeps will be critical for assessing methane input into the water column and atmosphere and for understanding associated chemosynthetic benthic communities. This area is also known to contain very high densities and a high diversity of deep-sea coral and sponge communities. Offshore central Oregon southward to northern California experiences extensive fishing by commercial vessels deploying bottom-contact gear and high coral and sponge bycatch. BOEM needs to better understand the portions of this region thought to have potential for siting wind energy infrastructure.
5. ***New England and Mid-Atlantic Canyons, Slope, Seamounts, and Seeps*:** The continental slope, canyons, seamounts, and methane seeps within this broad zone support diverse and often fragile and vulnerable habitats. They are considered biodiversity hotspots, with deep-sea corals and sponges, chemosynthetic communities supporting seep faunal assemblages (including microbial mats, mussels, and tube worms), and commercial, recreational, and protected species. Coral and sponge habitats provide important three-dimensional structure for many deep-water benthic communities and have been identified as habitat for certain commercially important fish and shellfish species. Their vulnerability to anthropogenic impacts has motivated research, monitoring, mapping, and conservation efforts in the Northeast, including the creation of large deep-sea coral protection zones.[15,16,17]

Cultural Heritage

Due to ubiquitous human presence in and use of the marine environment, there is potential for discovery of UCH in any water depth. UCH such as shipwrecks and submerged aircraft may be found anywhere in the marine environment. Many coastal areas still hold the potential for discovery of submerged pre-contact sites and paleocultural landscapes. As such, data collection for mapping efforts must consider the potential for UCH to be located within any survey area and

[15] NOAA National Marine Fisheries Service (2016) Fisheries of the Northeastern United States; Atlantic Mackerel, Squid, and Butterfish Fisheries; Amendment 16. Federal Register 81, 90246. https://www.federalregister.gov/documents/2016/12/14/2016-29811/fisheries-of-the-northeastern-united-states-atlantic-mackerel-squid-and-butterfish-fisheries

[16] NOAA National Marine Fisheries Service (2021) Fisheries of the Northeastern United States; Omnibus Deep-Sea Coral Amendment. Federal Register 86, 33553. https://www.federalregister.gov/documents/2021/06/25/2021-13293/fisheries-of-the-northeastern-united-states-omnibus-deep-sea-coral-amendment

[17] Executive Office of the President (2016) Northeast Canyons and Seamounts Marine National Monument. Federal Register 81, 65159. https://www.federalregister.gov/documents/2016/09/21/2016-22921/northeast-canyons-and-seamounts-marine-national-monument

be of sufficient quality and resolution to allow for their identification during data analysis and interpretation by archaeologists and heritage specialists.

Geographic areas of interest for paleocultural landscapes are influenced by local geology, sea level history, and preservation potential. Local sea level models should be consulted for specific areas of interest, because sub-regional variation is substantial. The following bathymetric contours on the U.S. outer continental shelf only provide a rough guide for where potential submerged landform features and submerged pre-contact archaeological sites may be encountered shoreward (shallower) of that depth:

- ***Gulf of Alaska/Bering Sea, 60 m (200 ft)***
- ***U.S. Pacific Coast, 140 m (460 ft)***
- ***U.S. Gulf of Mexico (primarily eastern and western Gulf), 60 m (200 ft)***
- ***U.S. Atlantic Coast, 120 m (400 ft)***

Archaeological and ecological characterizations UCH provide important baseline ecological information in unexplored and undeveloped areas. The ecological importance of shipwrecks and other UCH that provide substrate for marine biota applies everywhere and therefore calls for broad geographic exploration. It is common for UCH to be a key survey component within highly managed areas of the ocean, such as active or anticipated energy/mineral development lease areas and marine protected areas such as National Marine Sanctuaries or National Park Service Units. However, significant UCH resources are known to exist outside of these areas, and it is important to pursue OEC beyond these management boundaries. Regions of particular interest include the following:

- ***Along the Atlantic and Pacific seaboards***
- ***Alaska and the Aleutian Island chain***
- ***U.S. territories, particularly the Mona Passage***
- ***Gulf of Mexico and the Mississippi River Delta Front***
- ***Papahānaumokuākea Marine National Monument***
- ***National Marine Sanctuary of American Samoa***

Marine Resources

Due to the wide-ranging thematic priorities identified by the marine resources subgroup, the accompanying geographic priorities are similarly expansive. The white paper (Appendix C) provides more detail for each subgroup. Shared geographic priority areas (summarized below) include the ***Northeast U.S.*** (Fisheries Habitat, Aquaculture, and Renewable Energy themes), ***Marine National Monuments*** (Fisheries Habitat and Critical Minerals), ***Parts of the West Coast*** (Aquaculture and Renewable Energy), ***Alaska*** (Aquaculture, Deep Sand and Gravel, and Natural

Products), and ***Hawaii*** (Aquaculture, Renewable Energy, and Natural Products), and several ***other Pacific Islands*** (Critical Minerals, Natural Products, Aquaculture).

Many of the high priority geographic areas identified for the fisheries habitat thematic priority occur within Marine National Monuments and were identified by the subgroup as important habitats supporting recreational, subsistence, or commercial fishing and/or endangered species. These priority areas are in need of better mapping and exploration so that a more complete understanding can be obtained of the ecosystem processes critical to supporting these fisheries and the designation of future protected areas.

Critical marine minerals can and do occur throughout the U.S. EEZ, but the areas with high resource potential are much more limited. By focusing initial critical mineral-relevant exploration and characterization activities in areas of relatively high resource potential, the U.S. will get a head start on data collection in areas of likely future industry interest and simultaneously improve existing predictive models. Many of the geographic priorities identified are in the Central and Western Pacific, including some within Marine National Monuments, a status which does not preclude scientific research but may limit the types of sampling and prevents leasing. Identified priority areas for critical minerals include the deep abyssal plains and seamounts around Wake Island and the deep abyssal plains and Magellan Seamounts northeast of the Mariana Arc.

Similar to the critical minerals thematic priority, natural products may potentially be found anywhere in the ocean. Because higher biological diversity increases the likelihood of occurrence for biomedically and biotechnologically relevant natural product resources, consideration for selection of geographic priority areas for the natural products thematic priority focused on high diversity areas. This group chose to further prioritize the importance of exploration of new regions by specifically excluding geographic areas that had already received any previous natural product-focused field work, including the Aleutian Islands. Priority target areas requiring baseline mapping and exploration include the EEZ around Wake Island, Johnston Atoll, and Jarvis Island. Secondary priority areas (which have already been mapped for other purposes) include Guam, the seamounts between the Hawaiian Islands and Midway, and the northern (Arctic) coast of Alaska.

For the aquaculture thematic priority, the waters off the Aleutian Islands and the Gulf of Alaska, the leeward side of Oʻahu and the western side of Hawaiʻi the Big Island (Kona Area) of the Hawaiian Islands, Guam and Saipan, the waters in Southern California, and some regions offshore of the Northeast U.S. were identified as suitable for aquaculture development, pending further characterization.

Similarly, geographic priorities for the renewable energy thematic priority are potential regions of renewable energy (e.g., floating offshore wind and wave energy) development, pending environmental characterization. These regions include areas off the coast of Massachusetts, the west coast of the U.S., and Hawaii.

For the deep sand and gravel thematic priority, geographic areas of interest were close to regions with the greatest known demands for sand. These areas include a large region 114 miles off the west coast of south Florida, a region 60 miles off the South Carolina coast, an area 25 miles offshore of the Florida panhandle, and an area on the north shelf of Alaska.

Seafloor Hazards

The seafloor hazards subgroup identified five priority areas and *ranked them in order of priority*. They additionally assigned either "exploration" or "characterization" as the primary activity to be conducted for each region. "Exploration" was assigned where no baseline data are available, while "characterization" was assigned when baseline data already exists but more detailed information is needed.

1. ***Cascadia Subduction Zone Frontal Thrust and Splay Faults*** (Characterization): The high hazard potential and proximity of the Cascadia subduction zone to large population centers and important economic resources in the Pacific Northwest makes this a high priority area for hazard exploration and characterization. The subgroup also noted abundant opportunities to leverage field resources with other ongoing and planned scientific efforts in this region.
2. ***Submarine Volcanoes and Subduction Zone Areas of the Central Aleutian Arc*** (Exploration): The central Aleutian arc contains numerous subsea volcanic centers that pose volcanic and submarine landslide hazards. While the priority areas are listed as exploration targets, this is due to the lack of any baseline data. Detailed characterization of these areas would also prove invaluable. Volcanism along the Aleutian arc is driven by subduction of the Pacific Plate beneath the North American Plate and the region contains high priority areas for assessing subduction zone driven earthquake and tsunami hazards. The priority subareas are the Islands of Four Mountains, Bogoslof Island, the Shumagin Islands slope area, and the Unimak Island area.
3. ***Eastern Alaska-Aleutian Subduction Zone Area*** (Exploration): This area is within the rupture zone of the 1964 M9.2 great Alaska earthquake, which was the second-largest ever recorded in the world. This area is near the population and infrastructure center of Alaska. The inland and near-shore record of the 1964 earthquake is well documented, but the offshore understanding of the earthquake and subduction zone processes is lacking and is critical for improving our understanding and evaluation of earthquake and tsunami

hazards. Within this area are three regions of particular interest: Amatuli Trough and slope, southwest of Montague Island, and Middleton Island.

4. ***California Continental Borderland*** (Characterization): The California Continental Borderland is the offshore continuation of the diffuse plate boundary system, which onshore includes the San Andreas, Inglewood, and other earthquake generating faults. While efforts to characterize the active faults and landslides in this region have been ongoing for several decades, vital information necessary for earthquake/landslide hazard analysis and mitigation modeling is still unavailable due to the complexity of the deformation, incomplete mapping, and challenging conditions for paleoseismology. Of particular interest are: the Northern Channel Islands fault system, the Coronado Bank fault, and the Borderlands submarine landslide/tsunami hazards.
5. ***Northeast Caribbean*** (Characterization): The northeast Caribbean is a complex subduction zone plate boundary dominated by oblique subduction of the North American Plate under the eastern edge of the Caribbean Plate. The Hispaniola-Puerto Rico-Virgin Islands region is heavily populated and home to significant industrial infrastructure, so is constantly at risk of damage from earthquakes, tsunamis, and hurricanes. The primary regions/hazards that would benefit significantly from additional exploration and characterization in the northeast Caribbean are: the subduction zone; crustal faults; the backarc thrust zone (Muertos thrust belt); submarine landslides and tsunamis; and hurricane-driven coastal, nearshore, and offshore change.

Water Column

The water column subgroup identified the following areas:

- ***Aquaculture Opportunity Areas***: One top priority is to focus on defined geographic areas consistent with Aquaculture Opportunity Areas (AOAs; defined geographic areas designated by NOAA as suitable for commercial aquaculture).[18] Beyond AOAs, the FDA is especially interested in Southern California and Northeast areas given existing industry interest to develop commercial aquaculture sites and harvest commercial seafood in these areas.
- ***Arctic and North Pacific***: The Arctic and North Pacific are experiencing rapid regime shifts as a result of climate change. It is important to collect physical, biogeochemical, and biological oceanographic data to document such changes. These changes can be captured from long-term passive and active datasets, including acoustics, profiling floats, satellite remote sensing, and ship-based observations, which collectively can reveal the

[18] NOAA Office of Aquaculture. Website updated March 8, 2022. Aquaculture Opportunity Areas. https://www.fisheries.noaa.gov/national/aquaculture/aquaculture-opportunity-areas

characteristics and dynamics of geophysical, biological, and anthropogenic impacts on the water column environment.

- ***Gulf of Mexico***: The Gulf of Mexico (GOM) area includes the northern GOM and West Florida Shelf including south to Pulley Ridge. It spans temperate to tropical climate zones, and siliciclastic to carbonate seafloor geology and associated interactions with the overlying water column. The region is an area of interest due to a number of oceanographic features, trends, and events, including natural and anthropogenic stressors that impact biological systems (e.g., hypoxic zones, increased especially under concurrent stressors of temperature; petroleum pollution; acidification; changes to freshwater inflow; and harmful algal blooms). Water column chemistry in the GOM influences the U.S. Southeast and Mid-Atlantic coasts through hydrodynamic linkages including the GOM Loop Current and eddies, Florida Current, and Gulf Stream, and this connectivity should be further explored and characterized.
- ***Hawaiian Islands***: The Hawaiian Islands have diverse shallow-water environments, including coral reefs, that are susceptible to changing water column properties as well as the very deep pelagic environments that are poorly understood. This region offers both exploratory data collection in the very deep pelagic environments as well as historical data collection and monitoring near the islands in the shallower environments.
- ***Monterey Bay***: Monterey Bay is within the Monterey Bay National Marine Sanctuary, which includes the Monterey Canyon. The close proximity to deep water allows for easier study of both shallow and deep water column environments. The region has a wealth of existing information (biological, chemical, physical, etc.) that new water-column research can build on.
- ***Remote Pacific Islands***: The remote Pacific Islands are some of the least mapped and explored areas of the U.S. EEZ, and the water column is no exception. Like the Hawaiian Islands, the region is home to both diverse shallow-water habitats that are experiencing changing water column conditions and deep pelagic environments that are underexplored.
- ***Southeast United States***: Southeast U.S. coastal zone from Dry Tortugas, Florida Keys to North Carolina out to the 500 m bathymetric contour spans temperate to tropical climate zones, siliciclastic to carbonate seafloor geology and associated interactions with the overlying water column. It is highly influenced by Gulf of Mexico water through hydrodynamic linkages and associated stressors, as described above.

Public Input for Geographic Priorities

Aggregated public geographic priorities provided nominal overlap with those identified by Federal subject matter experts (see Figure 1) and included, in no particular order: the North Pacific, Pacific Islands, the Cascadia Margin, the Gulf of Maine, the Gulf of Mexico (specifically

the West Florida Shelf 'blue holes' and mesophotic benthic communities), the mid-Atlantic region (specifically the New York Bight), and Atlantic submarine canyons. Many areas of interest were identified primarily by their operational value: e.g., areas with the potential for significant critical mineral occurrences or demand for sand, those with high geohazard risk, important fish habitats, sensitive ecosystems, and areas with high economic potential such as regions with oil deposits or likely sites for renewable energy development.

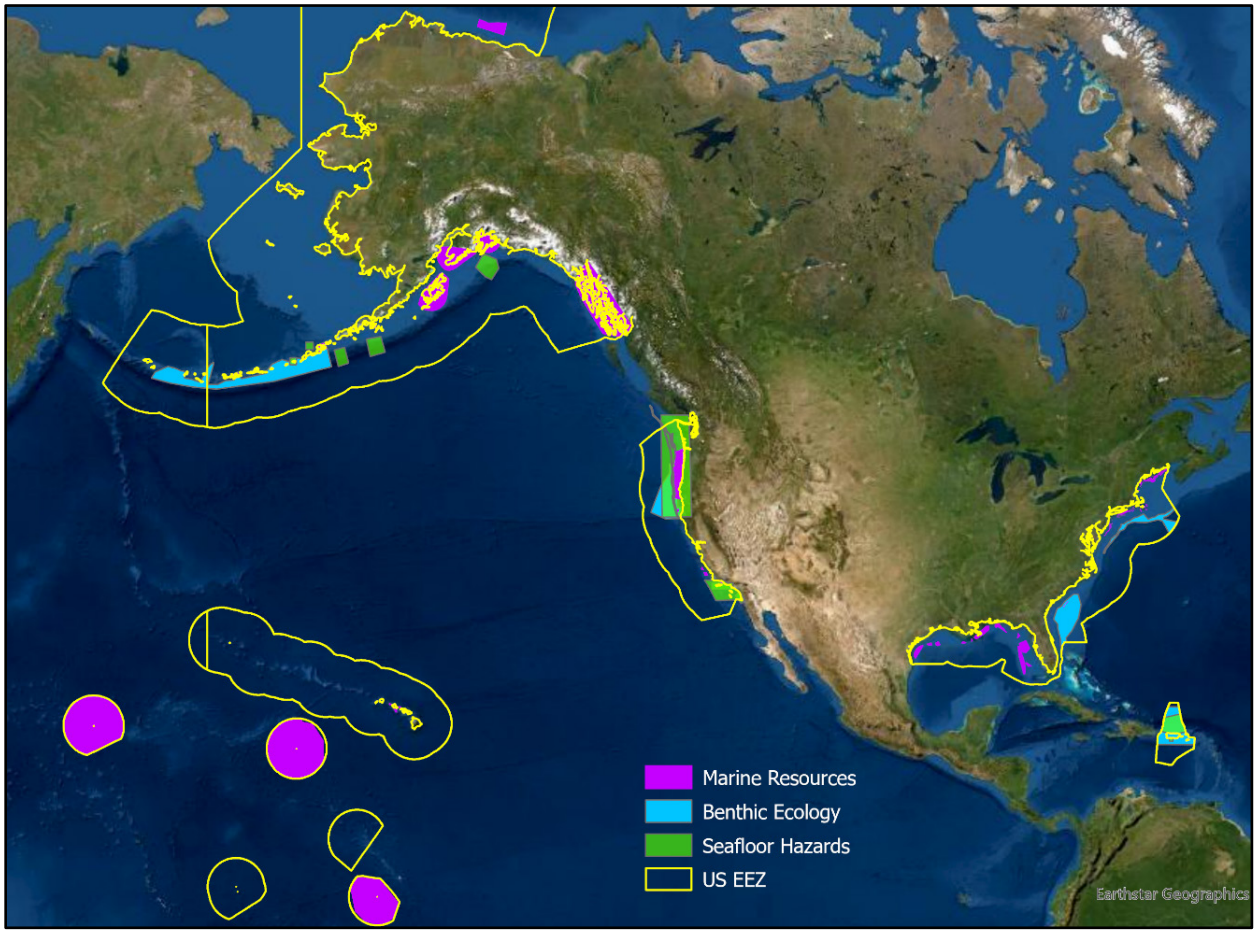

Figure 1. Map showing all geographic priority areas submitted by IWG-OEC subgroups. All polygons are attributed with contact information, data types requested, resolution requirements, and justification statements. Polygons will be made publicly available on the NOAA GeoPlatform.

Table 1. Matrix displaying overlap in priority areas identified by subgroup. Though only two of the five subgroups provided a ranked priority list, all subgroups identified geographic areas of interest.

Geographic Priorities as identified by subgroups					
	Benthic Ecology	Cultural Heritage	Marine Resources	Seafloor Hazards	Water Column
Aleutian Arc	X	X	X	X	X
Cascadia Subduction Zone	X	X		X	
Hawaiian Islands		X	X		X
Other Pacific Islands		X	X		X
Caribbean	X	X		X	X
California Coastal Region		X	X	X	X
Gulf of Mexico		X	X		X
Blake Plateau	X	X			
Northeastern U.S. and Seamounts	X	X	X		

Emerging Priorities

In addition to the themes addressed by the five subgroups, there are three additional priority topics for future OEC – climate change, biodiversity, and environmental justice – being actively considered by the Ocean Science and Technology Subcommittee and its various interagency working groups, including the NOMEC Council and the IWG-OEC. Ocean exploration and characterization data are highly relevant to addressing each of these three emerging priority areas. In the discussion below, we highlight some opportunities for NOMEC-associated activities to provide information needed to wisely manage resources, make policy decisions, and equitably engage affected communities.

Climate Change

The ocean acts as a sink for over 90% of the excess heat and approximately 30% of anthropogenic CO_2,[19] leading to ocean warming, acidification, and deoxygenation with subsequent impacts on the abundance, distribution, and diversity of marine fauna[20] that affect the functioning of ocean ecosystems and the benefits they provide to people. Sufficient data on even basic properties such as temperature and salinity are lacking in deep-sea environments, despite being crucial for monitoring and predicting climate change impacts. Conversely—as the National Academies of Science, Engineering, and Medicine explained—the ocean provides numerous opportunities for carbon dioxide removal[21] and other climate solutions, such as harnessing ocean renewable energy (e.g., offshore wind), protecting and restoring blue carbon in coastal and seabed environments, decarbonizing shipping, and storing carbon below the seafloor. One study concluded that a combination of such ocean-based solutions could provide up to one fifth of the annual emission reductions needed to achieve the 1.5-degree target by 2050.[22] Though blue carbon is widely known to be sequestered in coastal environments like mangroves, marshes and seagrass beds, there are also significant stores of carbon in the deep ocean, such as seabed sediments and methane hydrates. Information is lacking to fully evaluate their role in mitigating climate impacts. With the focus on exploring and characterizing unknown and poorly known parts

[19] IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar5/syr/

[20] Levin LA, Le Bris N (2015) The deep ocean under climate change. Science 350, 766-768. https://doi.org/10.1126/science.aad0126

[21] National Academies of Sciences, Engineering, and Medicine (2021) A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration. The National Academies Press. https://doi.org/10.17226/26278

[22] Hoegh-Guldberg O, Caldeira K, Chopin T, Gaines S, Haugan P, Hemer M, Howard J, Konar M, Krause-Jensen D, Lindstad E, Lovelock CE, Michelin M, Nielsen FG, Northrop E, Parker R, Roy J, Smith T, Some S, Tyedmers P (2019) The ocean as a solution to Climate Change: Five Opportunities for Action. World Resources Institute. https://oceanpanel.org/wp-content/uploads/2022/06/HLP_Report_Ocean_Solution_Climate_Change_final.pdf

of the ocean, ocean exploration and characterization activities conducted through the NOMEC enterprise are uniquely poised to provide critical data to help better understand climate impacts and inform climate-related decision making. Examples of relevant data include measurements of deep ocean temperatures and currents, carbon transport through the water column, carbon stored in seafloor sediments and hydrates, and a wide variety of ecological data to help monitor biological impacts and provide appropriate management options for climate mitigation and adaptation.

There are several areas in the report where climate change was noted as a factor in priority identification:

- The Cultural Heritage subgroup noted that climate change threatens UCH;
- The Marine Resources subgroup highlighted that climate change is expected to increase demand for sand and gravel;
- The Water Column subgroup identified the Arctic and North Pacific as geographic priorities, noting the rapid regime shifts the region is undergoing because of climate change.

Additionally, in all parts of the ocean, both benthic and pelagic organisms are already being impacted by climate change, and relevant exploration and characterization data should help managers to better monitor and respond to such changes.

Biodiversity

The planet is currently experiencing unprecedented acceleration of species extinctions, and approximately 91% of unknown biodiversity is estimated to be in the ocean,[23] including in the largely unexplored deep sea. Imaging technologies and collection of specimens using human-occupied, remotely-operated, or autonomous vehicles, and increasing use of rapidly evolving environmental DNA collection and processing (coupled with voucher specimens), will help to reveal much of this unknown biodiversity. The United States has a goal of conserving 30% of lands and waters by 2030.[24,25] To do so in a scientifically rigorous manner will require management-ready data on species abundance and biodiversity including rare and unique taxa. Studies that elucidate ecological mechanisms and system processes are key to understanding important

[23] *See* Mora C, Tittensor DP, Adl S, Simpson AGB, Worm B (2011) How many species are there on Earth and in the Ocean? PLoS Biology 9, e1001127. https://doi.org/10.1371/journal.pbio.1001127

[24] Executive Order No. 14008 (2021). https://www.govinfo.gov/content/pkg/DCPD-202100095/pdf/DCPD-202100095.pdf

[25] U.S. Department of the Interior. Website accessed March 22, 2022. America the Beautiful. https://www.doi.gov/priorities/america-the-beautiful

patterns. The deep sea includes hot spots of biodiversity and biomass, such as seamounts, canyons, and hydrothermal vents.[26] Organisms adapted to live in certain extreme environments that are relatively rare seem to be particularly vulnerable to extinction. For example, a recent assessment of endemic hydrothermal vent species found nearly two-thirds were threatened with extinction.[27] Ocean exploration and characterization data can help improve understanding of such organisms and environments and thereby inform sound management.

Several of the subgroups specifically identified biodiversity as a factor in their stated priorities:

- The Benthic Ecology subgroup noted the value that sensitive benthic habitats, such as coral and sponges, have in supporting biodiversity at the seafloor and in the water column (e.g., fisheries);
- The Cultural Heritage subgroup identified the capacity of UCH to serve as biodiversity hot spots;
- The Marine Resources subgroup noted the reliance of natural product discovery on biodiversity.

Environmental Justice

The concept of environmental justice is grounded in the reality that low-income and marginalized people, particularly Black, Indigenous, and other communities of color are disproportionately impacted by environmental harms, such as air and water pollution, extreme weather events, and other climate change impacts. Access to nature is also disproportionately lacking for such communities, which often have fewer opportunities to influence decisions that directly affect their wellbeing. Approaching environmental justice is a whole-of-government effort, with multiple Executive Orders directing agency action on the topic.[24,28,29] NOMEC has an important role to play in implementing these U.S. government goals. Members of the NOMEC Council and

[26] *See* Levin LA, Le Bris N (2015) The deep ocean under climate change. Science 350, 766-768. https://doi.org/10.1126/science.aad0126

[27] *See* Thomas EA, Molloy A, Hanson NB, Böhm M, Seddon M, Sigwart JD (2021) A Global Red List for Hydrothermal Vent Molluscs. Frontiers in Marine Science 8, 713022. https://doi.org/10.3389/fmars.2021.713022

[28] The White House (2021) Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis. Executive Order 13990. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-protecting-public-health-and-environment-and-restoring-science-to-tackle-climate-crisis/

[29] The White House (2021) Tackling the Climate Crisis at Home and Abroad. Executive Order 14008. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

IWG-OEC participated in a workshop hosted by the Ocean Science and Technology Subcommittee.[30] The NOMEC Council and its two IWGs will aim to:

- Make data accessible, relevant, and resonant to community needs;
- Strive for equitable cross-sector engagement;
- Promote workforce development;
- Build explicit, systemic workflows for considering environmental justice in projects;
- Improve engagement processes with Tribes and other Indigenous peoples;
- Engage local communities in two-way conversations;
- Increase representation of historically excluded communities in leadership and participant roles in NOMEC projects.[31]

Over the coming months, the NOMEC Council and IWGs will further develop and explore opportunities to incorporate environmental justice into activities and products.

Data Needs for Exploration and Characterization

Benthic Ecology

The benthic ecology subgroup highlighted data needs that fall into three general themes. Primarily, many respondents emphasized the need for prerequisite high resolution multibeam echosounder data, bathymetry, and acoustic backscatter information, particularly for identified geographic priorities one, two, three, and five. Additionally, characterizations for all geographic priorities require high resolution imagery and/or video of the seafloor to identify and describe organisms, marine resources, methane seeps, and associated geophysical features. Better characterization will also contribute to a better understanding of the biological, geological, and chemical processes that create diverse communities, productive ecosystems, and potential geohazards. Imagery is used to validate seafloor maps and habitat suitability models. Finally, particular physical sample types were identified as high importance for characterizations. Biological samples are used for taxonomy, reproduction, and genetic studies. Accompanying abiotic observations, ideally coupled with submersible in-situ observations when possible, such as physical, chemical, and biological oceanography data, are needed throughout all areas of interest as well.

[30] Subcommittee on Ocean Science and Technology (2022) Summary of SOST Environmental Justice Workshop. https://www.noaa.gov/sites/default/files/2022-02/SOSTEnvironmentalJusticeWorkshopPublicSummary.pdf

[31] Subcommittee on Ocean Science and Technology (2022) Opportunities and Actions for Ocean Science and Technology (2022-2028). https://www.whitehouse.gov/wp-content/uploads/2022/04/03-2022-SOST-Opportunities-and-Actions-for-Ocean-Science-and-Technology-2022-2028-1.pdf

Cultural Heritage

UCH sites are generally discovered during exploratory geophysical/hydrographic surveys utilizing data acquired by acoustic and magnetic sensors; specifically, multibeam bathymetry and backscatter, side scan sonar, sub-bottom profiler, and marine magnetometer. Investigation and characterization of UCH sites requires high-resolution (cm and sub-cm resolution) visual, optical, and acoustic data. This can be collected via remotely operated vehicles (ROV); autonomous underwater vehicles (AUV); video and photographic still imagery; or 3D scanning using laser, lidar, or sonar scanning systems**.**

Paleocultural Landscapes

BOEM's *Guidelines for Providing Archaeological and Historic Property Information*[32] provide a general template of the minimum standards for appropriate instrumentation, resolution, and reporting for paleocultural landscapes. Additionally, engagement with local Tribal Nations to access local knowledge including potential oral histories, resource extraction patterns, traditional ecological knowledge, and myths may provide guidance on Tribal interests and intersections with proposed projects.

Threats to/from UCH and Ecological Contributions

Higher-resolution data are necessary to characterize damage from natural and anthropogenic impacts as well as risk assessments for pollution. Sensors such as fluorometers and mass spectrometers can be integrated with AUVs, ROVs, towfish, and other instruments to detect and quantify hydrocarbons in the water column at UCH sites, whether leaking from the structures themselves or from external sources of pollution (e.g., oil spills). Metagenomic and metatranscriptomic analyses of microbial communities in sediment samples can identify taxa associated with hydrocarbon metabolism to determine if trace quantities of hydrocarbons are present. Oil fingerprint analyses from collected samples can identify the source of hydrocarbons and determine if they originated from the UCH (e.g., a sunken oil tanker) or are from an external source (e.g., oil spill or natural seep). Metal corrosion analyses can inform assessment of the potential pollution risk of 20th century submerged aircraft and watercraft that carried fuel, oil, or other pollutants on board. Metal corrosion analyses on shipwrecks of any age can also provide indices of microenvironmental conditions associated with climate change, including ocean acidification, temperature, and salinity fluctuations.

[32] Bureau of Ocean Energy Management (2020) Guidelines for Providing Archaeological and Historic Property Information. https://www.boem.gov/sites/default/files/documents/about-boem/Archaeology%20and%20Historic%20Property%20Guidelines.pdf

To understand the ecological contributions of UCH, sites need micro- and macro-biological characterizations via traditional visual surveys; species sampling via collection, DNA and environmental DNA (eDNA) community structure analyses to compare biological hotspots within a regional framework, and bioacoustic assessments for community structure and interconnectivity analyses. In addition to biological assays, physical and chemical oceanographic studies are also needed for baseline conditions such as water temperature, salinity, dissolved oxygen, pH, etc. to develop a more comprehensive characterization of conditions on and around submerged UCH.

Marine Resources

Very broadly, technology and data requirements overlap between all thematic priorities identified by the marine resources subgroup and include water column chemistry, seafloor maps, photography, and geologic, geochemical and biological data; all obtainable through research vessels and deployable assets. Seagoing vessels are needed for offshore bathymetric mapping and backscatter collection, water column sampling, box coring, and to host remotely operated and autonomous platforms. Additionally, ROVs and AUV operations are needed for seafloor sampling (biological, chemical and geological), detailed (sub-meter resolution) mapping and seafloor photography, and high-resolution geophysics. Use of these technologies would provide data for exploring and characterizing fisheries habitat, aquaculture sites, sites for renewable energy, and occurrences of critical minerals. In addition to these data, basic oceanographic data (depth, temperature, salinity) and procedures for collecting samples of sufficient size and in ways that preserve microbiological samples and minimize cross-contamination are needed for greater study of natural products that may be beneficial for human uses.

Seafloor Hazards

All priority areas for seafloor hazards require ship-based multibeam echosounder bathymetry (10-20 m scale), backscatter, water column, and sub-bottom profiler data. Additionally, each priority area requires ship-based sediment coring (piston/vibracore/gravity/multi-coring). The majority of the priority areas require ROVs and high resolution (cm to m scale) AUV/ROV mapping, including bathymetry, backscatter, water column, sub-bottom imaging, and photographs; multi-channel seismic reflection data (spark or airgun, depending on the location); and ship-based gravity and magnetics data. A select number of priority areas require ROV-based geological grab samples and repeat multibeam sonar surveys.

Water Column

The water column subgroup affirmed the data needs identified by Netburn (2018),[33] which developed a toolbox of physical, chemical, and biological measurements for water column exploration. These toolbox measurements include temperature, density, salinity, oxygen, fluorescence, bathymetry, light transmission, ocean color, genomics, biological specimens, *in situ* imaging, and active acoustics. More specific data needs identified by the subgroup included chemical or physical signatures of upwelling, oceanographic anomalies (e.g., cold water fronts and 'super chill events'), atmospheric methane, acidification, and long-term measurements of ambient noise to distinguish sound source. Finally, the subgroup identified several biological data types and their associated water column dynamics (such as mixed layer dynamics) that are necessary for appropriate exploration and characterization of the environment: characterization of harmful algal blooms and their dynamics (e.g., hypoxic/anoxic layers); acoustics for fish and zooplankton movement and biomass patterns; and eDNA with concurrent specimen sampling for validation. In all areas, the group emphasized the need for higher spatial and temporal resolution.

Public Input

Primary data types identified by public input are those fundamental to basic characterization of water and sediments: temperature, oxygen, turbidity, and salinity sensors, bathymetry and backscatter measurements, and dissolved gas measurements. Groups also identified biogeochemical and physico-chemical data (including benthic fluxes) as valuable indicators of ecosystem health and a changing ocean; both types are necessary to accurately monitor climate change and other anthropogenic impacts.

Pursuant to the thematic focus on ecosystem assessment, public input also recommended basic ecosystem sampling and biomass measurements. Machine learning and artificial intelligence were identified as technologies which could be leveraged to facilitate more efficient characterization of benthic and water column communities. Respondents suggested both technologies be employed to video and photographic data recovered to rapidly and accurately develop species catalogs in conjunction with greater use of eDNA analyses. Remotely and autonomously operating vehicles continue to be a focus for ocean exploration and characterization.

[33] Netburn AN (2018) From Surface to Seafloor: Exploration of the Water Column (Workshop Report). NOAA Ocean Exploration. https://doi.org/10.25923/rnjx-vn79

Relevance to Emerging Priorities

While all data types and methods in Table 2 are important and relevant to understanding and dealing with climate change and loss of biodiversity and its benefits, a few types of information are especially relevant:

- Climate change – biological sampling, water column acoustics, video/imagery, biogeochemistry and water characteristics
- Biodiversity – biological sampling, water column acoustics, and video/imagery

Consideration must be taken as to how such data are archived, synthesized, and presented in order to consider environmental justice.

Aligning the identified data types and methods with emerging domestic and international priorities will be an ongoing, iterative process that will inform and guide future NOMEC and IWG implementation activities.

Table 2. Matrix displaying overlap in relevant data types and methods across exploration and characterization subgroups.

	Benthic Ecology	Cultural Heritage	Marine Resources	Seafloor Hazards	Water Column
Multibeam bathymetry	X	X	X	X	X
Multibeam seafloor backscatter	X	X	X	X	X
Side-scan sonar		X	X		
Sub-bottom profiler	X	X		X	
Marine magnetometer		X	X	X	
Biological sampling	X	X	X	X	X
Geological sampling (e.g., coring, ROV grab samples)	X		X	X	
Water column acoustics	X	X			X
Video/imagery	X	X	X	X	X
3D scanning		X			

Biogeochemistry and water characteristics (e.g., turbidity, fluorometer, temperature, salinity, DO, pH, current profiles, contaminants, nutrient loading)	X	X	X		X
Multi-channel seismic reflection				X	
Satellite/aerial based optical and radar imagery and altimetry			X		X

Challenges

Subgroups were tasked with identifying existing challenges to OEC. Subgroups identified cost and remote locations of expeditions and surveys as primary limitations to OEC, particularly in the deep ocean. As one public respondent noted, complete exploration of the EEZ is currently impossible and will become feasible only through unforeseen increases in national survey capacity. The effects of limited spatial and temporal sampling are amplified within the water column and for seasonal phenomena given the dynamic and transient nature of water masses. Extended time series are valuable for characterization but require dedicated resources that would otherwise be deployed elsewhere. These challenges often cause areas of the EEZ to be only superficially explored and characterized. New and enhanced high endurance or high-resolution technology with machine learning capabilities may provide a viable solution to such challenges, and modeling projects using strategically gathered water column data can help interpolate between sampling gaps. In addition, cooperation in the form of combining program resources, leveraged funding, and sharing expertise of the various research, exploration, and resource management entities can help mitigate exorbitant logistical costs. The National Oceanographic Partnership Program is one example entity that can help to better leverage resources across the public and private sectors to advance OEC.

Once data have been collected, the challenges of data storage, processing, accessibility to data products, and data security must be addressed. Trained personnel are needed to synthesize data and standardize archiving and metadata at a resolution, fidelity, and consistency useful for marine resourcing and other applications. Such challenges are amplified by both the quantity of data or origin from multiple platforms, instruments, and sources, which complicates interoperability. These issues were echoed in the public input: for all data produced from OEC efforts, public response emphasized interest in easily accessible and easily operable data. For example, groups identified a need for clear metadata standards, a central database for storage, a focus on principles of ethical data handling and dissemination, and data packetization and visualization for easier public consumption. The importance of appropriate cataloging and curation also extends to physical specimens, which should be made widely accessible to communities of interest, especially when government funds contributed to their collection.

To make data accessible to non-Federal stakeholders, transferring results across communities is needed, especially for analysis of UCH finds, which require coordination with Tribal nations and other relevant partners before releasing any data. Engagement and collaboration with Tribal Nations, Indigenous populations, and other underserved communities must be proactive and respect any intellectual property restrictions. Researchers do not consistently have experience with partnering and meaningful engagement, and these efforts can be time consuming. This

challenge can be addressed by engaging communities (Tribes, non-profits, etc.) early in project development, identifying culturally appropriate research methods, and by requesting if any needs can be served to those communities as part of the proposed project and adapted as necessary.

A more complete documentation of challenges identified by subgroups is available in Appendix A.

Conclusions

The U.S. EEZ is vast and contains diverse features and natural resources. Some areas remain completely unexplored while others require more comprehensive characterization. Interest in and need for ocean exploration and characterization information is rapidly expanding, as such information is needed in order to better understand the individual biogeochemical and physical processes and components of the integrated ocean system that determine both current and future oceanographic conditions, including projected shifts due to a changing climate. Accurate characterization of this integrated ocean system is essential for our understanding of its resiliency, our ability to predict future changes, and for informing conservation, management, and the development of sustainable uses. The NOMEC Strategy recognized and addressed these realities by requiring prioritization of national strategic priorities for OEC in order to highlight the most pressing and cross-cutting needs and guide Federal efforts accordingly. This priorities report is a living document which will be updated periodically to reflect progress and shifting strategic needs. The IWG-OEC is fully cognizant of interagency national security concerns regarding data protection, specifically as it relates to undersea critical infrastructure (both human-made and bathymetric), and is committed to ensuring that threat awareness discussions remain a key factor in developing its priorities list. This initial report serves as a planning resource for agencies and the broader ocean exploration community. For example, a notable takeaway for planning future fieldwork is the clear confluence of interest from multiple subgroups in specific geographic areas including the Aleutian Islands, Blake Plateau, U.S. Caribbean, and Cascadia Margin, which is a direct result of ongoing, multi-agency efforts to explore and characterize these regions. However, despite these efforts, there remains much work to be done; utilizing, expanding, and improving upon current cross agency strategies to explore and characterize these regions will help get us there.

Each priority identified in this report has near-, mid-, and long-term achievable goals, milestones, and deliverables requiring continued discussion with all Federal and non-Federal entities, stakeholders, and groups to solidify order of operations and goals. Fortunately, the thematic and geographic exploration and characterization priorities identified in this report are ripe for multi-

sector and multi-disciplinary partnership engagement and coordination. Indeed, the nature of OEC activities requires not only cross-disciplinary cooperation, but also interagency and multi-sectoral collaboration — including industry, NGOs, philanthropy, and academia — in data collection and sharing. Some of these efforts are already ongoing, such as the multi-agency/multi-sectoral "EXPRESS" (Expanding Pacific Research and Exploration of Submerged Systems) partnership that is successfully coordinating field work on the Cascadia Margin.[34] This OEC priorities report can inform other such collaborations planning localized field projects or regional campaigns and help advance shared exploration and characterization needs.

List of Appendices

Appendix A - White paper submissions
https://noaa.gov/sites/default/files/2022-10/NOMEC_OEC_Priorities_Report_Appendix_A.pdf

Appendix B - White paper template
https://noaa.gov/sites/default/files/2022-10/NOMEC_OEC_Priorities_Report_Appendix_B.pdf

Appendix C - 2020 Federal Register notice responses
https://noaa.gov/sites/default/files/2022-10/NOMEC_OEC_Priorities_Report_Appendix_C.pdf

Appendix D - 2022 Federal Register notice responses
https://noaa.gov/sites/default/files/2022-10/NOMEC_OEC_Priorities_Report_Appendix_D.pdf

[34] Rudebusch J. Website updated May 5, 2021. Expanding Pacific Exploration and Research. U.S. Geological Survey. https://wim.usgs.gov/geonarrative/express/