Appendix C - benthic ecology white paper

Subgroup: Benthic Ecology
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Subgroup interests and disciplines represented: This subgroup consisted of representatives from varied disciplines, including benthic ecology, fish biology, zoology, oceanography, biology, marine biology, genetics, geophysics, habitat suitability modeling, physical scientists, as well as program, research and science coordinators.

Themes & topics that are of highest priority:
Themes and topics of importance to this subgroup included biodiversity hotspots, vulnerable marine ecosystems, essential fish habitat, commercially important species, critical minerals, wind energy siting and permitting, marine aquaculture, marine resources, geohazards, habitat suitability modeling and validation, protected areas, biogeochemical cycling, connectivity, mesophotic and rariphotic coral reefs, chemosynthetic communities, cold seeps, cold-water corals (CWC), coral mounds, coral gardens, submarine canyons, protected species, anthropogenic impacts, conservation, sample collection, taxonomy, sponge grounds, species distributions, and coral and sponge fishery bycatch.

Description of Geographic Priority Areas:
Priority 1: Aleutian Islands & Slope: With the limited mapping and exploration that has occurred around the Aleutian Islands, we know that the surrounding water hosts some of the densest and most diverse CWC 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 coral and sponges. Further, in the many unexplored areas, species distribution models predict a number of biodiversity hotspots of structure-forming invertebrates. Much of the habitat around the Islands and in the Gulf have only sparse bathymetric and other habitat-related data, and most visual observations have been limited to glimpses of the shelf edge or shallower. In deeper water beyond the shelf, little of the slope and submarine canyons have been mapped, explored or characterized. Aside from the high potential of CWC, sponge, and fish community discoveries, BOEM has identified targeted areas of Alaska in the Aleutian Arc which potentially hold marine minerals. The federal waters off of Alaska also offer some of the most promising opportunities for growth of marine aquaculture. All of these opportunities

for discovery require some degree of seafloor mapping data acquisition prior to visual observations and sample collections. This work would be mostly exploratory at this time.

Priority 2: Southeast U.S. Blake Plateau and "Million Mounds": This priority area consists of five interconnected regions of the Central and Western Blake Plateau (BP): 1) the relatively shallow Carolina-Georgia shelf and slope areas at depths of 30-500 m, total area ≈ 22,600 km2; 2) the deeper Western and Central BP and "Million Mounds" area South of Stetson and Savannah Banks and East of Canaveral Banks at depths of 350-750 m, total area ≈ 29,600 km2,; 3) Central BP Mounds East of the Carolina-Georgia shelf/slope, at depths of 750-860 m, total area ≈ 3,350 km2; 4) the BP Knolls, south of Central BP Mounds at depths of 800-860 m, total area ≈ 1,859 km2; 5) Eastern and Southern Richardson Reef Complex at the Eastern edge of the BP, depths of 700-900 m, total area ≈ 176 km2. The total area within the boundary encompassing these areas is ≈ 99,927km2. The Carolina - Georgia Shelf and Slope is the largest contiguous nearshore data gap in the Northeast Atlantic between 30-500 m depth. The primary justification for benthic habitat characterization in this area is the heterogeneity of habitats - sand, rocky reef, canyons and bioherms of *Oculina*, *Lophelia* and other CWCs, as well as commercial and recreational species (e.g. snapper/grouper). The Central and Southern BP contains large unmapped areas of CWCs and sponges between 350-900 m that are unrivaled in the US and may be the largest aggregation of CWC reefs/mounds in the world. Recent multibeam mapping and habitat suitability modeling for the main reef-building CWCs *Lophelia pertusa* suggest that more extensive habitat exists at offshore reefs (e.g Richardson Reef Complex), mounds (e.g. Million Mounds and Central BP) and knolls, yet little of this area has been characterized. These CWC aggregations may have significant importance for regional biogeochemical cycling and connectivity of deep-sea species. These reefs also experience extreme temperature variability and it is thus critical to understand their niche envelope and how future ocean change will impact reefs in this area.

Priority 3: Mesophotic and Deep Habitats throughout the U.S. Caribbean EEZ: This priority covers the Caribbean EEZ including Mona Passage, North and South of Puerto Rico and waters surrounding the U.S. Virgin Islands (USVI; St. Thomas, St. John, and St. Croix). This region harbors live bottom, coral gardens, submarine canyons, mesophotic reefs, iron-manganese nodules and trenches at depths between 30 – 8300 m; total area ≈ 85,855 km2. Caribbean shallow-water reefs are very well characterized, but reefs in mesophotic and rariphotic zones remain poorly known. The few recent dives by the Nautilus and Okeanos Explorer revealed a high potential for further discoveries including new species. The proximity of the deep-sea to land and the expansion of offshore fishing in the area make it a priority for benthic habitat/essential fish habitat characterization and provides an opportunity to characterize unique habitats extending across depth zones. The Puerto Rico Trench, where the Caribbean plate collides with the North American plate, remains one of the few trenches left to be explored.

Priority 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. Priority 4 includes the Cascadia Margin proper, as well as the Mendocino Ridge to the south and important commercial fishing grounds off the coasts of Oregon. The Cascadia Margin stores a high volume of methane and baseline characterization of the seeps will be critical for assessing methane input into the water column and atmosphere. In particular, seafloor habitats and sedimentary systems greater than 1,500 m along the Cascadia Subduction Zone are poorly known. Further, this area is known to contain very high densities and a high diversity of CWC and sponge communities as well as chemosynthetic communities near seeps. Offshore central Oregon southward to northern California experiences extensive fishing by commercial vessels deploying bottom-contact gear, making the Priority 4 one of the highest areas of coral and sponge bycatch on the West Coast. The Bureau of Ocean Energy Management is also interested in portions of

Priority 4 as potential wind energy sites. Gorda Ridge, included in Priority 4, is the only mid-ocean spreading center in the US EEZ.

Priority 5: New England and Mid-Atlantic Canyons, Slope, Seamounts and Seeps: This priority area consists of three interconnected regions: 1) the relatively shallow submarine canyon heads and intercanyon continental slope off the Northeast continental shelf from Heezen Canyon at the Hague Line south to Wilmington Canyon off Delaware Bay, at depths from 100 to 500 m, total area = ~18,000 km2; 2) the Northeast Canyons and Seamounts Marine National Monument comprised of four New England Seamounts within the EEZ and three submarine canyons on the nearby slope (NCSMNM total area = ~12,400 km2); and 3) methane seep anomalies found along the continental margin.
The continental slope, canyons, seamounts, and methane seeps support diverse and often fragile and vulnerable habitats and are hotspots of biodiversity containing uncommon or rare species (e.g., CWCs and sponges; chemosynthetic communities supporting seep faunal assemblages including microbial maps, mussels, and tube worms) as well as commercial, recreational, and protected species. Those with CWC 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 stimulated research, monitoring, mapping and conservation efforts in the Northeast, including the creation of large CWC protection zones. Some exploratory work has been conducted, particularly in NCSMNM, but more targeted sampling is needed throughout the region. Multibeam bathymetric maps are lacking for much of the area encompassing the canyon heads and inter-canyon region.

Data needs:

There are similar data needs for benthic characterization among priorities that can be grouped into 3 general themes: (1) Many respondents emphasized the need for prerequisite high resolution MBES, bathymetry and backscatter information, particularly for Priorities 1, 2, 3, and 5. (2) Following, characterizations for all priorities require high resolution imagery and/or video of the seafloor to quantify the organisms, habitats, marine resources, methane seeps, and associated geophysical features,and also to understand the biological, geological, and chemical processes that create diverse communities, productive ecosystems, and potential geohazards. Imagery is also used to validate seafloor maps and habitat suitability models. (3) Samples are of 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 bio-oceanography data, area needed throughout all areas of interest as well.

Relevance to national security, conservation, and/or the economy:

Priority 1: Coral and sponge fishery bycatch is a major issue and it is essential to assess these habitats and understand these ecosystems before further inflicting long-term damage and impacting ecosystem function. Consequences would have direct impacts on the Alaskan and US economy, and could threaten food security nationally. If targeted areas are deemed appropriate for aquaculture in Alaska, these efforts could bolster the US economy by introducing an additional source of seafood without contributing further pressure on the natural environment. Slope areas off the Aleutian Islands are seismically active and geological surveys can improve assessments of marine geohazards including earthquakes, landslides, and tsunamis.

Priority 2: This area supports commercial and recreational fisheries which is of interest to the SAFMC as well as other stakeholders. The SAFMC has classified a large portion of this area as a coral protected area, yet the Central BP Mounds and Knolls are not protected. Large portions within the coral protected area remain poorly characterized. Economically, the ports and harbors of Savannah and Charleston are an economic engine in the South. The human population is growing rapidly with many commercial and recreational fishermen. The offshore reefs hold immense ecological value for reef and pelagic fishes, sharks, sea turtles, dolphins, and whales. The region also has energy potential, including oil, gas and wind energy, as well as mineral resources.

Priority 3: The Puerto Rico Trench creates a high potential for geohazards due to the possibility for earthquakes and tsunamis, thus posing significant risks for PR and USVI. At the other end of the depth spectrum, mesophotic coral ecosystems harbor unique biodiversity that should be conserved. They also provide essential fish habitat for commercial and recreational fish species, which have been overfished in shallower waters. Mineral resources exist North of the PR Trench. Added benefits of exploration in PR and USVI include economic stimulation, potential training opportunities to students at local universities, and outreach and public engagement.

Priority 4: The Cascadia margin seeps provide significant ecosystem services, including habitat for commercially important fishes and support for diversity along the continental margin. Methane seeps are also biological hotspots for krill, plankton, and crustaceans, which in turn sustain higher trophic levels (e.g., whales). Methane-derived authigenic carbonates serve as a hard substrate for CWC and sponges on millennial time scales. Focused research in this priority area will elucidate the relationship among seep environments, CWCs, sponges, fisheries, and other organisms and provide new insight into subduction zone and hydrate-associated fluids in this important seismogenic zone.

Priority 5: The relatively shallow heads of the canyons and upper inter-canyon slope areas support commercial and recreational fisheries and of interest to the New England and Mid-Atlantic Fishery Management Councils. Distinct and abundant chemosynthetic habitats in this region may also support commercial fisheries and their conservation is relevant to potential oil and gas exploration and utilization. Although the two Councils have classified much of the area between the seaward boundary of the priority area and the EEZ as CWC protection zones, many of the shallower areas in the canyon heads are not protected. Upper inter-canyon slope areas are ecotones and upwelling areas used by protected species (marine mammals). Additionally, seamounts and canyons within the NCSMNM, support abundant and diverse deep-sea coral communities that contribute significantly to the area's conservation value as well as supply habitat for commercially and recreationally important species.

<u>From your perspective, what makes this area unique?</u>

Priority 1: The steep continental slope stretching from south of Kodiak Island to the maritime boundary with Russia is a remote and remarkably unexplored area. While limited observations of the Aleutian Islands revealed globally unique coral and sponge "gardens" - data is essentially absent from the slope in deeper depths. As an active subduction zone on the Ring of Fire, it is astounding that this dynamic area connecting an ecologically important archipelago of islands with an oceanic trench has so little known about it.

Priority 2: The relatively shallow Carolina-Georgia shelf includes rocky habitats and live bottom in mesophotic and rariphotic depths. The Central and Southern Blake Plateau contains large areas of CWCs and sponges between 350-900 m that are unrivaled in the US and may be the largest aggregation of CWC reefs/mounds in the world. The Richardson Reef Complex may be one of the largest in the world, with over 3,000 features and a total length of ≈ 150 km. The Gulf Stream and topographic steering due to seafloor features such as the Charleston Bump contribute to the extensive corals and productive fisheries. The Central Mounds and BP knolls are predicted to be suitable habitats for CWCs yet are not protected. Exploration and characterization of the BP region will improve understanding of the northern and southern extents of the BP mounds, knolls and reef complex features and the factors that control their distributions.

Priority 3: The Puerto Rico Trench, where the Caribbean plate collides with the North American plate, remains one of the few trenches to be explored. The potential to find species new to science, as well as previously unknown cold seeps exists. Mesophotic coral ecosystems (MCEs) consist of light-dependent corals and associated communities found at depths ranging from 30–40 m and extending to over 150 m in tropical and subtropical regions. They are populated with organisms typically associated with shallow coral reefs, such as corals, macroalgae, sponges, and fish, as well as species unique to mesophotic depths or deeper. As the documented decline of shallow coral reefs continues, it is important to understand the value and role of mesophotic coral ecosystems. Not only do shallow and mesophotic ecosystems share common species, but they both serve as essential fish habitat for economically and ecologically important species. In the U.S. Caribbean, of the few MCEs that have been characterized, we have documented that these habitats serve as a refuge for overfished commercial species such as grouper and snapper that are rare in shallower waters.

Priority 4: The margin contains CWC, sponge, and chemosynthetic habitats that provide a wealth of ecosystem services, including serving as nurseries and feeding grounds for commercially important species and environments that contain marine natural products. Modern seafloor bathymetry in the area suggests a diverse array of seafloor substrates where geologic processes contribute to a range of diverse interactions between complex seafloor topography, fluid seepage and ecosystems. However, relatively little is known about the extent and diversity of these deep-sea habitats. Given that preliminary studies indicate some of the highest densities of CWCs on the West coast, this region includes locations of potentially high biodiversity. This area also contains potential key sites for offshore wind development. In order to facilitate the siting and permitting of offshore wind projects and balance the needs of multiple users as well as conservation goals, this area must be characterized.

Priority 5: Each canyon or seamount appears to be unique and may have its own geological and biological signature. Additional CWC and/or seep habitats are often discovered during scientific missions, suggesting that many of our marine resources remain unknown. The NCSMNM is particularly unique, with three entire canyons that are relatively well explored and with seamounts that are ecologically significant and sensitive. Seep habitats on the Atlantic margin support highly abundant and distinct benthic communities. Few seep habitats have been explored in this region, but further characterization may provide important information on biological connectivity and overall geochemical dynamics of methane seepage along the entire U.S. Atlantic margin.

<u>List the partners or organizations that may also be interested in these areas:</u>

Partners and organizations that may also be interested in these areas are categorized below.
Fishery Management Councils: South Atlantic, Pacific, North Pacific, New England, Mid-Atlantic, and Caribbean. **Federal Agencies:** NOAA - OER, DSCRTP, NMFS, OHC, OCS, NCCOS, ONMS, OAQ, AFSC, NWFSC, SWFSC, SEFSC, GARFO, National Systematics Lab; BOEM, USGS USFWS, NSF. **States:** CA, OR, WA, AK, NC, SC GA, FL, ME, NH, MA, CT, NJ, VA, State SeaGrants. **Other:** SeaGrant, Smithsonian Institution, Department of Natural Resources Puerto Rico, British Geological Survey, Schmidt Ocean Institute; OOI, Woods Hole Oceanographic Institution (WHOI), MBARI, Department of Fisheries and Oceans, Canada, Mid-Atlantic Regional Council on the Ocean, British Geological Survey, GEOMAR, Woods Hole Oceanographic Institution. **Academic partners**: University of Maine, University of Rhode Island, University of Connecticut/Mystic Aquarium, Temple University, LeHigh University.

Existing technologies that can currently support data collection and those that need improvement:

Existing technologies that can support all priorities include use of multibeam mapping systems to collect high resolution bathymetry and backscatter, and various high-resolution imaging and/or collecting gear such as AUVs, ROVs, HOVs, and drop and towed camera systems. Better systems are needed to collect high-resolution multibeam data in the 200-500 m depth range. Simultaneous collection of physical/chemical water column data (AUV and/or CTD) may provide information necessary to improve understanding of species distributions, connectivity patterns, and to refine habitat suitability models. The ability to collect specimens via ROVs or HOVs is critical to our understanding the diversity of organisms. Improved image analyses systems and programs (Artificial Intelligence and Machine Learning) and new tools for collection of specimens would greatly improve and expedite data collection and processing. 3-D cameras would aid in taxonomy and fine-scale spatial distributions of organisms. Such information is of particular benefit for improved CWC habitat suitability modeling to predict distribution of CWC taxa across regional landscapes. In remote areas where weather and sea conditions can be challenging (e.g. Aleutians), deployment of autonomous platforms (e.g., saildrone multibeam mappers, AUVs, etc.) may provide distinct advantages for mapping and exploration under these conditions. Environmental DNA (eDNA) techniques can also be further developed to be collected and processed on a wider variety of platforms, and processed more quickly in the laboratory. Water column eDNA samples may improve the characterization of food webs, allow detection of rare or invasive species, and documentation of bentho-pelagic coupling. At cold seep sites, technologies such as ROVs, and HOVs would allow for sampling of fauna and geologic samples that can constrain the timing of methane emissions through geochronology while documenting species distributions and habitats as a function of depth and latitude along the continental margin. Water column imaging (EK60/80 and/or multibeam WCD data) conducted before and after seafloor explorations would capture active methane plumes and constrain temporal variations in seep emissions.

What are the challenges to gather data? How could they potentially be overcome?

Generally, exploration and characterization missions require large ships with oceanographic capabilities, submersible vehicles and other equipment capable of surveying extreme depths, and relatively smooth conditions to deploy and recover submersibles and to adequately map the seafloor. The cost of exploration and characterization missions is also prohibitive given the technology, the overall sizes of the features of interest, duration of the expeditions and, at times, needing to survey the same location multiple times. For very remote or far offshore priorities like Alaska, the Pacific Islands, and the Caribbean for example, there is a lack of available research vessels in particular. Many days at sea are exhausted by long transit times, limiting time for mapping and surveying. Limitations are also present at mesophotic depths. Many vehicles and mapping systems cannot effectively operate in relatively shallow areas, such as in waters off the Carolina-Georgia shelf and the heads of canyons, so these areas are often bypassed. If tech divers are used to survey mesophotic depths, the area that can be characterized is also limited and will likely require multiple missions. Further, lost fishing gear can also pose real hazards to survey technology and are difficult to avoid at steep features such as canyons. A combination of challenges mentioned above have resulted in superficially surveyed priorities and areas of interest which leaves significant portions of the EEZ that still need to be fully characterized. However, many regions have been able to overcome the above challenges to gather critical data related to the benthic ecology of many deep-sea systems. Cooperation, in the form of combining program resources, leveraged funding, and expertise of the various deep-sea research, exploration, and resource management entities has proven to be an effective solution.

Figures:

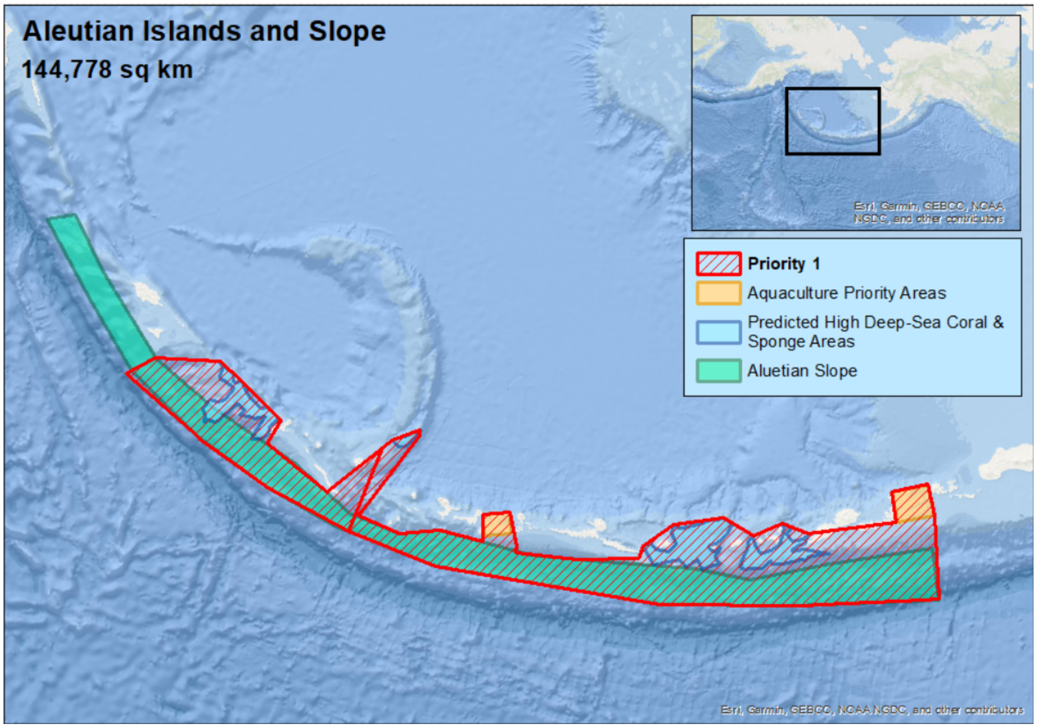

Figure 1. #1 Priority of the Benthic Ecology Group. This area encompasses 3 different priority areas nominated by the subgroup participants.

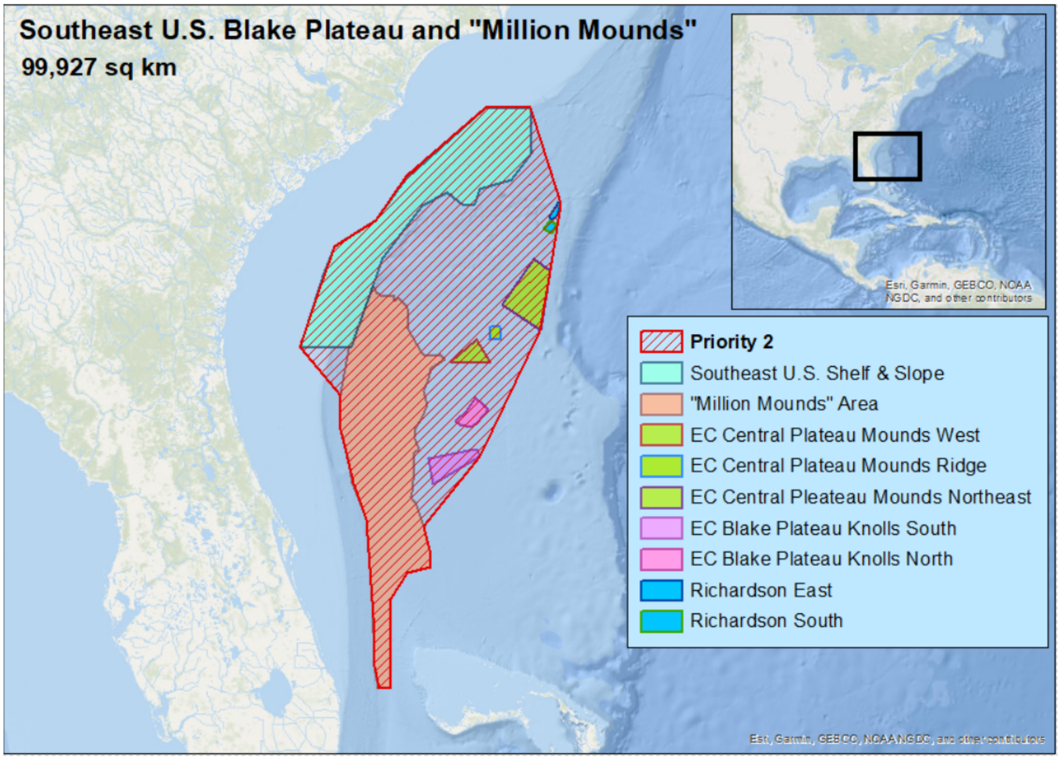

Figure 2. Priority 2 of the Benthic Ecology Group. This area encompasses 9 individual priority areas nominated by the subgroup participants.

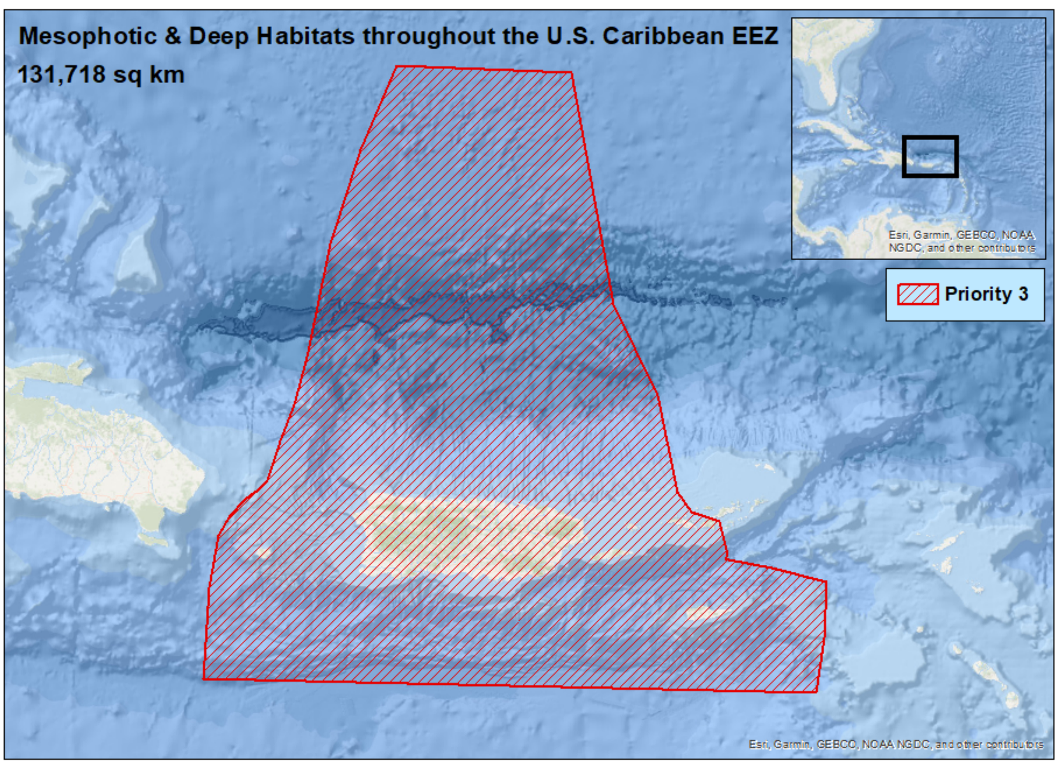

Figure 3. Priority 3 of the Benthic Ecology Group. This area encompasses most of the Caribbean EEZ.

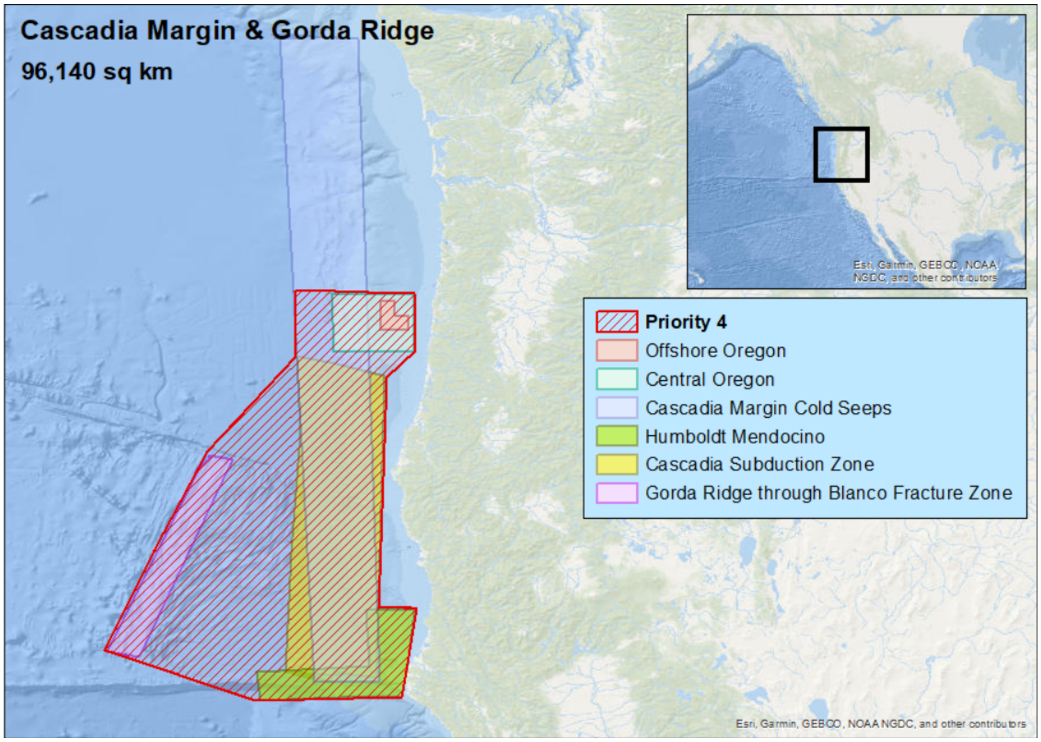

Figure 4. Priority 4 of the Benthic Ecology subgroup. This area contains 6 different priority nominations by the subgroup participants.

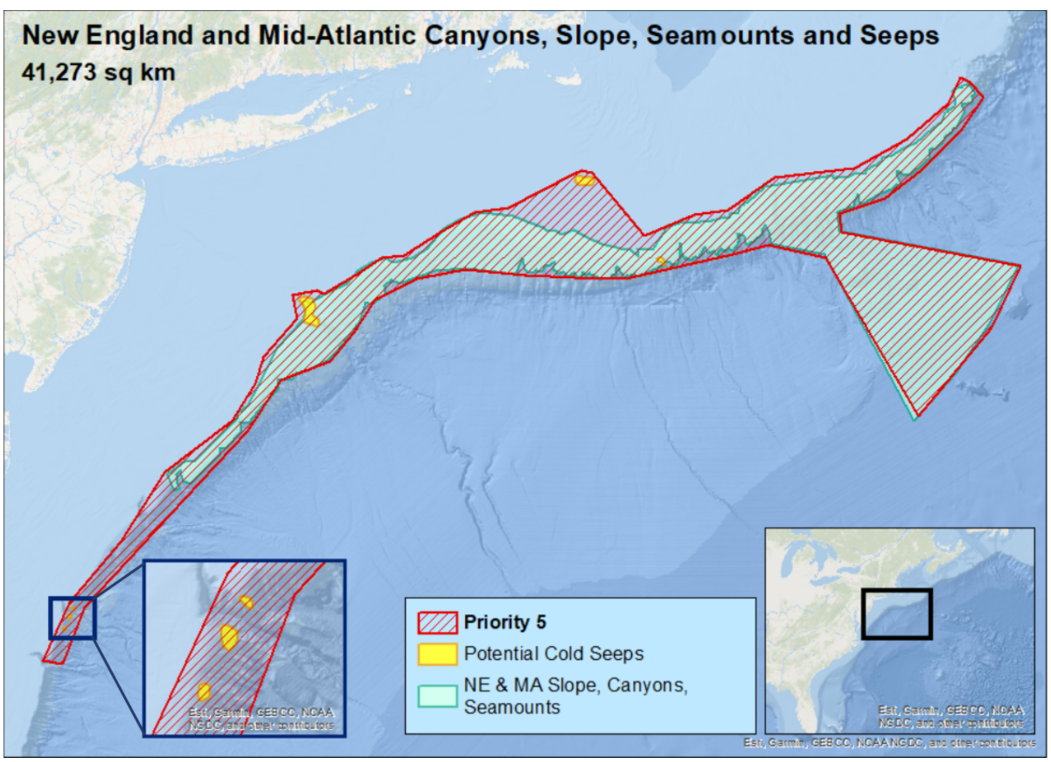

Figure 5. Priority 5 of the Benthic Ecology group. This area encompasses 2 priority areas nominated by the participants.

Appendix C - cultural heritage white paper

Interagency Working Group on Ocean Exploration and Characterization

National Ocean Exploration & Characterization Priorities in the US EEZ
White Paper Submission Form

Subgroup: Cultural Heritage
Co-leads: Frank Cantelas (NOAA) and Dave Ball (BOEM)
Collaborators (including agency represented): Laura Brothers (USGS), Alexis Catsambis (NHHC), Dave Conlin (NPS), Melanie Damour (BOEM), Chris Horrell (BSEE), Doug Jones (BOEM), Eirik Thorsgard (BIA), Hans Van Tilburg (NOAA)

Introduction (Description of subgroup interests and disciplines represented):
Exploration and site characterization related to underwater cultural heritage (UCH) focus on discovering and assessing UCH sites that reflect or are associated with events, people, a contributing design or construction, and the potential to contribute information significant to history of all cultures now associated with the US EEZ. While there are specific, tangible attributes associated with the physical remains of UCH such as shipwrecks and sunken aircraft, a toppled lighthouse, or a drowned pre-contact site, there are also the intangible values and connections that submerged places have to people in the past and present (e.g., origin stories, ceremonial locations, cultural view sheds, oral traditions and more). Exploration and characterization can include a variety of topics and types of UCH that are of interest to the government, NGOs, Tribal Nations, indigenous and other underrepresented communities, and the public. Some of those themes include: 1) major naval/military battlefields, 2) historical routes that trace the global slave trade (e.g. Atlantic triangle trade and coastwise Gulf of Mexico trade); 3) trade and migration routes and ports of call such as the Manila Galleon trade in the Pacific or the maritime activity occurring in the Atlantic and Caribbean; and 4) early human migrations into the Americas.

Exploration and discovery of UCH engages historians, archaeologists, cultural resource managers, anthropologists, native practitioners, indigenous communities and Tribal Nations, and others. Exploration of UCH is much more than just identification of archaeological sites; it is the meaning that people ascribe to these sites and locations. Tangible and intangible elements of our heritage help form the basis of our cultural identity.

Characterization typically focuses on ground-truthing potential UCH sites to answer specific research questions, or from a regulatory perspective to assess integrity and significance for listing on the National Register of Historic Places.

Exploring and characterizing UCH serves complementary functions, and carries the potential for entirely new datasets regarding the interface between cultural and natural resources. Rather than focus on a number of particular geographic areas of interest, and given the omnipresent nature of UCH, the intent of this white paper is to demonstrate the need and flexibility of incorporating studies on the inter-relationship between natural and cultural resources in mapping and characterization efforts more broadly.

Please list the themes/topics (e.g., critical minerals or wind energy for Marine Resources subgroup) that are of highest priority for your subgroup. These need not be ranked. (limit 200 words):
Previous ocean exploration/characterization workshops have identified a number of research priorities (see Appendix 2). For the purposes of this exercise, the Cultural Heritage IWG-OEC (CH IWG-OEC) sub-group identified the following general themes:

- *__Paleocultural Landscapes:__* The outer continental shelf (OCS), once subaerially exposed during the last glacial period, may still contain evidence of early human migrations into the Americas as well as exploitation and occupation of these now-submerged landscapes. Many of these areas also correspond with oral histories of Tribal Nations that live or once lived near the present coastline and still have important meaning for those Tribes today.

- *Threats to and from UCH:* Climate change, natural disasters, and anthropogenic activities can all directly impact UCH. However, UCH can present an environmental hazard vis-à-vis potentially polluting shipwrecks (and particularly concentrated in WWII naval battlefields such as Saipan and Midway, among others) or create seafloor navigational hazards.
- *Ecological Contributions of UCH:* Wooden-hulled and metal-hulled historic shipwrecks and to a lesser degree aircraft wrecks are hotspots of biodiversity and provide important artificial reef habitats for microbial communities and benthic fauna.

Description of Geographic Priority Areas (maximum of five (5), in ranked order):

UCH can be found in any water depth in the marine environment, therefore OEC efforts in all areas have the potential to discover UCH. Numerous examples exist of multi-disciplinary research related to UCH (c.f., Bethencourt et al. 2018; Damour et al. 2016; Little et al. 2016). Rather than identify specific ranked priority areas, the CH IWG-OEC encourages all future exploration and characterization efforts to consider the potential to include UCH in any planned missions, and to deliberately seek opportunities to partner with Tribal Nations and indigenous and other underrepresented communities. Below are a few examples that support the general themes identified above.

Paleocultural Landscapes:

Oral histories and traditional knowledge of many Tribal Nations tell of a time when ancestors lived beyond the current coastline, and evidence of intact landform features and pre-contact archaeological sites have been identified in several areas of the OCS (c.f., Braje et al. 2020; Pearson et al. 2014; Stanford et al. 2014). An example is the incredibly significant 8,000-year-old Manasota Key Offshore Site in Florida. The formerly inland mortuary pond that is now offshore in State waters is the first underwater pre-contact archaeological site discovered on the OCS to contain preserved human remains (Florida Department of State 2021). Yet, as Dixon and Davis (2020:5) note, “the role these regions played in the way humans evolved, colonized the globe, responded to sea level rise, and developed maritime adaptations remains virtually unknown.” To better identify and protect these areas from future extractive activities on the OCS, exploration surveys to refine regional paleocultural landscape models and characterization surveys (including collection of sediment cores) of high-potential areas are essential.

Geographic areas of interest are influenced by local geology and sea level history, and local sea level models should be consulted for specific areas of interest. However, the following bathymetric contours on the US OCS provide a general guide for where potential submerged landform features and submerged pre-contact archaeological sites may be encountered shoreward of that depth: Gulf of Alaska/Bering Sea, 60 m (200 ft); US Pacific Coast, 140 m (460 ft); US Gulf of Mexico (primarily eastern and western Gulf), 60 m (200 ft); US Atlantic Coast, 120 m (400 ft). Local sea level models should be reviewed to accurately identify potential areas of interest. Additionally, researchers should consult with local Tribes to incorporate traditional knowledge and agree upon appropriate research strategies and opportunities for collaboration (Ball et al. 2015). Previous ocean exploration/characterization workshops identified similar research priorities (Appendix 2), including: Kelp Highway (COL 2020a:45); Submerged Landscapes*, Human Coastal Migration, and Early Maritime Adaptations* (COL 2020b:55-60); Gulf of the Farallones NMS Shipwrecks and Submerged Prehistoric Landscape (OET 2014:22-23); and Channel Islands Early Sites and Unmapped Wrecks (OET 2014:33-39). A general discussion of the importance of this research priority and methodology can be found in the Submerged Landscapes white paper (COL 2020b:55-60). “The opportunity for major discoveries and key paradigm shifts regarding human evolution and cultural development are likely to result from the study of submerged landscape archaeology” (Dixon and Davis 2020:7).

Appendix C - cultural heritage white paper

Threats to/from UCH and Ecological Contributions:
Archaeological and ecological characterizations of UCH in unexplored/undeveloped areas can provide important baseline ecological information. Although the ecological importance of shipwrecks applies everywhere and therefore calls for a cross-cutting approach, areas for exploration with potential follow-up site characterizations include those outside active or anticipated energy/mineral development lease areas and outside present or anticipated National Marine Sanctuaries or National Park Service Units, along the Atlantic and Pacific seaboards, Alaska (and particularly the Aleutian Island chain), and US territories (and particularly the Mona Passage, connecting the Atlantic Ocean to the Caribbean Sea off Puerto Rico). Additionally, pertinent areas may also include those within areas of federal agency management or authority that have drawn less attention such as the eastern Gulf of Mexico.

Likewise, characterizations of UCH in areas that are heavily developed and/or have been impacted by climate change, natural events, or anthropogenic activities (e.g., hurricanes, submarine mudslides, oil spills like the 2010 *Deepwater Horizon* spill, trawling, etc.) would provide comparative, time-series datasets to inform long-term monitoring efforts, document cumulative impacts for environmental analyses, and assess ecosystem recovery after human-caused and natural disasters. One area for focusing characterization efforts could include the central and western Gulf of Mexico, especially the Mississippi River Delta Front—a region that experiences submarine mudslides, sea level rise, hurricanes, and anthropogenic impacts such as oil spills.

In contrast, marine protected areas such as the National Marine Monuments and Sanctuaries in the Pacific Ocean, which are managed areas ostensibly preserved from large-scale anthropogenic impacts, can provide further comparative datasets and meet agency missions. Areas for focusing characterization efforts, therefore, include regions such as the Papahānaumokuākea Marine National Monument and the National Marine Sanctuary of American Samoa.

Finally, individual, known, but non-located wreck sites sunk as target exercises or otherwise throughout the 20th century can provide a *terminus ante quem* for environmental research studies that measure the growth and formation of benthic communities over time. Examples include a series of German U-boats sunk 50 miles off the coast of Boston following World War II, or a series of US Navy vessels sunk in the Puerto Rico trench in the 1970s for fleet reduction purposes.

Provide a list or brief description of the data needed within each priority area:
UCH 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. To adequately identify potential UCH, processed acoustic data resolution should not exceed 1 m and survey lane spacing should result in no less than 150% overlap of multibeam, backscatter, and side scan sonar data. Magnetometer data should be collected at no less than 30 m (100 ft.) survey lane spacing with a sensor height-above-seafloor at no greater than 6 m (20 ft.). Investigation and characterization of UCH sites requires higher-resolution (cm and sub-cm resolution) visual, optical, and acoustic data that 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:
Over the past decade advancements in remote sensing, global positioning, modeling of Late Pleistocene coastal environments, and data collection from submerged paleocultural sites (e.g. DNA sampling, parametric sub-bottom profiler, Human Altered Lithic Detection), have raised the prospect for identifying high-potential sites and better understanding migration, original settlement, and the important and relevant relationship between cultural history and sea level change (Figures 1 and 2). Regional geophysical exploration surveys that include, at a minimum, high-resolution multibeam bathymetry and sub-bottom profiler, are necessary to understand the

potential presence of intact submerged landform features that may be associated with paleocultural landscapes. BOEM's Guidelines for Providing Archaeological and Historic Property Information 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, if oil samples can be collected, 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.

To understand the ecological contributions of UCH, sites need micro- and macro-biological characterizations via traditional visual surveys; species sampling via collection, DNA and 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 gather a more complete idea of conditions on and around submerged UCH.

Finally, baseline characterization of the UCH itself should also be completed utilizing photography/photogrammetry, comparison with historic plans, corrosion rate studies, marine hazard assessment for pollutants, and a general characterization of discernable archaeological site formation processes.

Describe relevance to national security, conservation, and/or the economy:
Identifying the location of UCH sites through exploration and scientifically characterizing them are key for implementing long-term ocean conservation strategies.

Paleocultural Landscapes:
- *National security:* directly related to long-term implications of human adaptation to sea level and climate change.
- *Economic:* need for understanding potential sites of significant UCH in the offshore environment, particularly in areas that coincide to wind energy development corridors (i.e., federal agency responsibilities to protect potentially historic properties under the National Historic Preservation Act).
- *Conservation:* acknowledgement of cultural heritage and legacy of underrepresented populations; capacity to engage in cross-cultural collaboration and forge interagency, Tribal, academic, and private partnerships; participation by Tribal education programs (including youth programs and Tribal Colleges and Universities) in marine mapping and characterization and identification of other conservation and economic uses.

Threats to/from UCH and Ecological Contributions:

- *National Security:* UCH can serve as navigational hazards to US government activities, installations, and exercises. Knowing the location of UCH that may create potential submerged hazards for survey equipment, submarines, etc. is important for maintaining control of these areas. US military-related activities in the EEZ may affect other Federal agencies' missions, decision-making, and UCH management responsibilities. Documenting the locations of UCH, especially unanticipated discoveries such as the US Navy Destroyer USS *Peterson (*DD-969) in a newly leased block in the northern Gulf of Mexico, is necessary for meeting cultural resource management responsibilities across Federal agencies with overlapping jurisdictions. The US government, in most cases, maintains ownership of sunken military craft, whether purposefully disposed or accidentally lost, and is responsible for any environmental or other threats they may pose.

  More than 1,500 sunken military vessels (ships and submarines) and over 3,500 military aircraft under the jurisdiction of the Department of the Navy are distributed across U.S. waters. Similarly, there is a sizeable number of foreign sunken military craft located in US waters representing the complex history of the nation. These vessels may serve as maritime gravesites for personnel lost in service to the nation, carry unexploded ordnance or oil/fuel, or even carry state secrets as in the case of the sunken nuclear-powered submarines USS *Scorpion* and USS *Thresher*. Likewise, lost aircraft may contain sensitive or secret technology; lost military ships, submarines, and aircraft may contain conventional, chemical, or nuclear ordinance that would pose a threat to the surrounding environment—and a grave threat to the US and our partners if recovered by a hostile party. As technology becomes more widely available, more reliable, and easier to use, locating, accessing, and recovering materials from these sites becomes easier to do for non-state actors.

- *Conservation:* UCH such as historic shipwrecks**—**wooden-hulled and metal-hulled**—**are known to serve as artificial reefs supporting diverse and often abundant biological communities. The deposition of ship and aircraft wrecks on the seafloor results in the introduction of potentially billions of calories and hectares of habitable substrate into ecosystems that may be fragile in the sense that they are composed of relatively few species with few overlapping biological niches, or biological deserts. With the introduction of calories and substrate and a known *terminus ante quem*, researchers have a starting point for longitudinal studies of biological succession and colonization, and the development of complex ecosystems from simpler ones, in varying marine habitats. These studies have direct applicability as models for the recovery and resilience of biological systems impacted by global climate change and large-scale environmental catastrophes such as the 2010 *Deepwater Horizon* oil spill.

  The ecological role of UCH and their influence on marine microbial community formation and biogeography is only beginning to be addressed (Hampel et al. In Review, Hamdan et al. 2021, Price et al. 2020). Marine microorganisms, including bacteria, archaea, and fungi, are the first to colonize anthropogenic inputs into the marine environment such as shipwrecks, and evolved to perform specific metabolic functions (e.g., iron sulfate reduction, wood degradation, hydrocarbon degradation, etc.). As marine microbial communities grow and expand across the shipwreck-seawater interface, the resulting biofilm provides chemical cues to free-floating larva and invertebrate organisms such as corals and sponges that the shipwreck is suitable for further colonization. Sessile invertebrate colonization, in turn, attracts motile organisms such as crustaceans, fish, and other fauna. Over time, each shipwreck site forms a small-scale ecosystem supporting diverse micro- and macrofauna and may even serve as ecological stepping-stones for larval dispersal. Deepwater shipwreck sites, often isolated from other seafloor features such as natural hard-bottom reefs and chemosynthetic communities, can function as "oases" of life on an otherwise featureless seafloor (Figure 3).

UCH site preservation is influenced by a variety of factors including the biochemical processes of degradation in the marine environment (Bethencourt et al. 2018; Björdal 2012a, 2012b; Johnson et al. 2006a, 2006b) as well as impacts from natural and anthropogenic events and activities (Anderson et al. 2017; Chaytor et al. 2020; Damour et al. 2016; Mugge et al. 2019a, 2019b; Salerno et al. 2018; Wright 2016). Anthropogenic impacts consist primarily of commercial fishing and bottom trawling, industrial/energy development and their associated seafloor-disturbing activities (e.g., anchoring, pipeline and cable installation, coring/borehole sampling, dredging, pile driving, and well spudding and mudsplays), and oil spills/pollution (Figure 4). Site disturbance, unauthorized artifact removal, commercial salvage, and looting have traditionally posed notable anthropogenic impacts as well.

UCH itself can pose an environmental threat to the surrounding environment. Preliminary research indicates that, of the approximately 20,000 sunken craft in US waters, a few hundred of them potentially contain large quantities of oil and other pollutants that could pose environmental harm. NOAA identified nearly 100 shipwrecks known or suspected to pose a substantial pollution threat, the majority of which are associated with World War II casualties during the Battle of the Atlantic (Symons et al. 2014). Other potentially polluting shipwrecks of concern have been identified along the Atlantic, Gulf of Mexico, and Pacific shores (including Pacific Island territories) though not all have been located.

Other considerations include the proper and consistent management and dissemination of UCH locational data across Federal agencies and with appropriate stakeholders while simultaneously ensuring their protection from illicit or destructive activities conducted without archaeological oversight. Efforts to ensure a consistent management strategy for UCH are necessary to communicate the appropriate information without potentially compromising their integrity or preservation. In addition, promoting awareness of UCH within the broader scientific community, industry/operators, other stakeholders, and the public will allow for its proper consideration in the development of scientific research projects, commercial/industrial activities, and energy/resource exploitation, as well as unanticipated discoveries of UCH in the marine environment.

Exploration mapping and site characterization studies will provide the necessary data to improve management strategies, protection, stabilization, and mitigation of previously damaged UCH.

- Economy: UCH provides unique opportunities for the recreational and sport diving communities to explore and learn about human history, as well as support local businesses. Recreational/sport diving in states such as Florida contributes to a robust economy heavily dependent on tourism. Heritage tourism opportunities such as Florida's Maritime Heritage Trail encourage divers to visit designated shipwreck sites in State waters and learn more about each site's identification and history through underwater signage and markers. Education and outreach about UCH through heritage tourism, in turn, fosters an appreciation for preserving these non-renewable cultural resources for the benefit and enjoyment of future generations. Ecosystem Services Value studies quantify the economic value of various natural resources and habitats including those in the marine environment (Hattam et al. 2015). Research to date has *not* quantified the ecosystem services provided by UCH, neither as revenue generators from cultural and heritage tourism nor as ecological habitats, therefore their contribution to the economy remains poorly understood, but is likely of increasing value.

  Potentially polluting aircraft and watercraft from the 20th century pose a series of risks to nearby ecological resources such as coral reef habitats, fish, and marine mammals, including fisheries and oyster farms, as well as to coastal communities that rely on marine resources for subsistence and commerce and tourism (Landquist et al. 2013, Michel et al. 2005, Monfils 2005). Deterioration of UCH due to climate change-related impacts (e.g., increases in severity and frequency of tropical storms, ocean acidification, sea level rise, and temperature rise) as well as other natural and anthropogenic impacts will affect sectors of the economy associated with heritage tourism and historic preservation. Public education and awareness—which enhances the appreciation of UCH—can also be a positive driver for the economy in terms of tourism and recreational water sports such as scuba diving and snorkeling (Cohn and Dennis 2013).

As indicated above, shipwrecks form inadvertent artificial reefs and act as stimulants for ecological complexity, increased biodiversity, and thereby increased populations of fish that are commercially valuable. Properly managed, these sites could form part of a larger program of sustainability in seafood harvesting.

From your perspective, what makes each priority area unique?
Exploration for and characterization of preserved submerged landform features on the Alaska and continental US OCS can provide evidence of early human migration into the western hemisphere and can better inform our understanding of the effects of sea-level rise on coastal archaeological sites and human response to changing coastal environments.

Wooden-hulled shipwrecks located in the deep waters of the Mona Passage may be well-preserved and unimpacted by anthropogenic activities such as industrial or energy development. Historic shipwrecks in this area date from the 15th through the 20th centuries and can provide important information on early Spanish exploration and slaving activities, piracy and privateering, and maritime commerce and natural resource extraction spanning more than 500 years.

The Mississippi River Delta Front (MRDF) area off the coast of Louisiana provides opportunities for data collection that will inform the identification of environmental threats both to and from UCH (Figure 5). Numerous known and potential UCH, including potentially polluting 20th century watercraft, have been identified within the MRDF, an area prone to frequent submarine mudslides due to complex dynamics between riverine outflow, underlying geology, and oceanographic forces. Expected impacts in the US from global climate change include an increase in the frequency and severity of tropical storms as well as increased flooding events in Midwest regions of the Mississippi River watershed, both of which may influence MRDF mudslide occurrence. Hurricanes—which also regularly impact the Louisiana coast—by themselves pose significant threats to UCH near the coast as well as in water depths exceeding 60 m (200 ft.) (Gearhart et al. 2011), even in the absence of induced mudslides. The MRDF also contains significant oil and gas infrastructure development. Mudslide impacts to both infrastructure and historic shipwrecks have already occurred (Chaytor et al. 2020), and subsequent occurrences risk the release of hydrocarbon pollutants from shipwrecks or from industrial sources that, in turn, may impact submerged and coastal cultural heritage sites.

Please list other partners or organizations that may also be interested in these areas:
Numerous academic institutions, Tribal governments, indigenous communities, and federal and state agencies have expressed interest in various aspects of UCH research.

What are the existing technologies that can currently support these priorities and what types of technology needs to be developed/improved upon to advance data collection/planning/processing techniques?
Currently available acoustic and magnetic geophysical/hydrographic survey instruments (e.g., multibeam echosounder, side scan sonar, sub-bottom profiler, marine magnetometer) have been used for decades to successfully identify potential UCH (both submerged pre-contact and historic sites). However, acoustic data resolution must be high enough so that UCH can be distinguished from natural geological or bathymetric features and hard-bottom habitats. Current advancements in Autonomous Surface Vehicle (ASV) capabilities and force-multiplier strategies to maximize and increase the efficiency of data acquisition in shallower waters will

enhance our ability to identify potential UCH. Additionally, recent experiments on human altered lithic detection from sub-bottom profiler survey data have shown promising results for identifying buried pre-contact archaeological sites that contain worked stone tools (Grøn et al. 2020).

With the anticipated enormous quantity of data that will be acquired under the NOMEC mapping strategy, development of machine learning/artificial intelligence tools to identify potential UCH in these datasets will be needed to streamline and maximize the efficiency and accuracy of data interpretation. Machine learning tools are already being developed for benthic habitat mapping and seabed classification (Marsh and Brown 2009, Landmark 2016), as well as identifying shipwrecks in side scan sonar data (Zhu et al. 2019, Nayak et al. 2021). Encouraging more innovations with machine learning to focus on identifying potential UCH in various types of datasets will be of great benefit. In addition to machine learning, human staff with UCH expertise must also be included in development plans.

The parametric sub-bottom profiler is a tool offering much higher resolution of shallow sub seafloor sediments than Chirp systems now widely used in the US. Using this new technology in lieu of or in addition to Chirp will undoubtedly increase our ability to resolve paleocultural landscapes that might contain pre-contact sites. The technology, more widely used in Europe, is not currently a standard tool in the US.

Sub-centimeter-resolution imagery collected via 3D optical or acoustic sensors (e.g., 3D laser/sonar/lidar scanning) provides critical data for assessing as well as quantifying degradation of UCH during site characterizations (Figure 6) (Damour 2020; Damour et al. 2019). Repetitive 3D scans of sites inform long-term monitoring efforts and developing best management practices that can be tailored to individual sites.

What are the challenges to gathering data or getting what is needed to assess? How could these challenges potentially be overcome?

Due to the random nature of their distribution there is a potential for discovery of UCH in any water depth. UCH such as shipwrecks and submerged aircraft may be found *anywhere* in the marine environment, while many areas along the coast 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 be of sufficient resolution to allow for their identification during data analysis and interpretation by archaeologists.

Collecting quality sub-bottom data to identify paleocultural landscapes may require a slower vessel speed than standard multibeam data acquisition does, making it more costly to collect. This challenge can be overcome by budgeting ship time for optimal collection for both multibeam and subbottom data, or having a very targeted sub-bottom survey nested within a larger multibeam survey.

While hull-mounted multibeam echosounders collect acoustic and backscatter data of sufficient resolution in shallower waters (<200 m) to identify potential UCH, in deeper waters (>400 m), these same systems may not achieve sufficient resolution of the seafloor to allow for identification of UCH. Instead, the use of AUVs integrated with multibeam echosounders and programmed to survey at a 30- to 50-m altitude above the seafloor is more advantageous.

In addition, UCH may be recorded in datasets collected for non-archaeological purposes (e.g., benthic habitat mapping, hydrographic surveys, seabed classification surveys, etc.) and remain “undiscovered” and undocumented in perpetuity until those datasets are analyzed by a qualified marine archaeologist. Coordination and communication between the archaeological community and the various NOMEC mapping efforts is necessary to ensure that UCH are adequately considered and identified across all relevant efforts.

Appendix C - cultural heritage white paper

Additionally, engaging/partnering with Tribal Nations, indigenous, and other underrepresented communities remains problematic. Researchers do not always have experience with partnering and meaningful engagement, and these efforts can be time consuming. This challenge can be overcome 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 adapt as necessary – this is above and beyond normal tribal consultation as part of the Section 106 process and is time consuming.

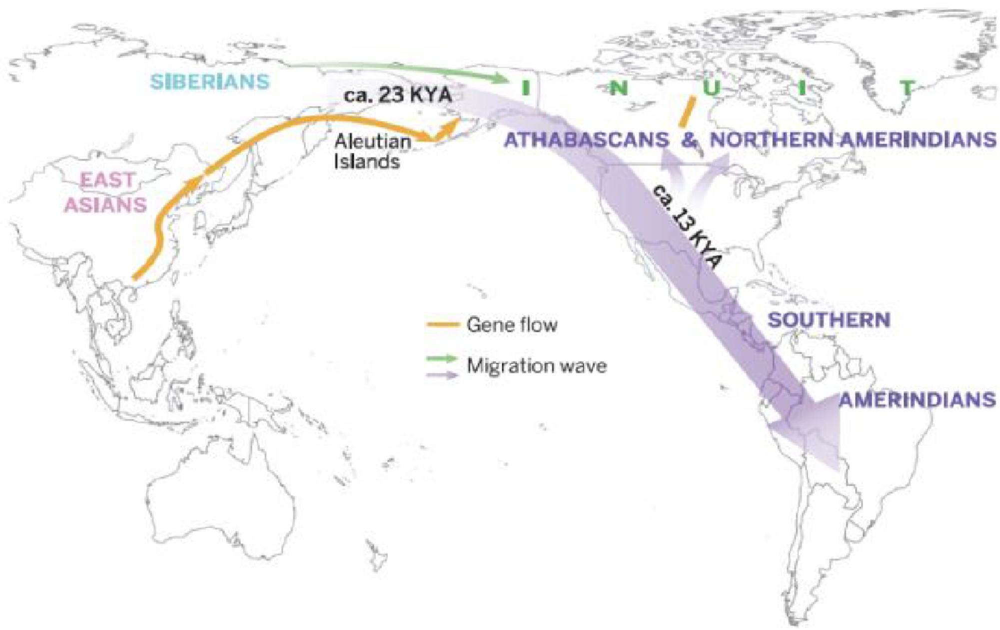

Figure 1. Map showing the route of initial human migration into the Americas as reconstructed from ancient skeletal genetic records (Raghavan et al., 2015).

Appendix C - cultural heritage white paper

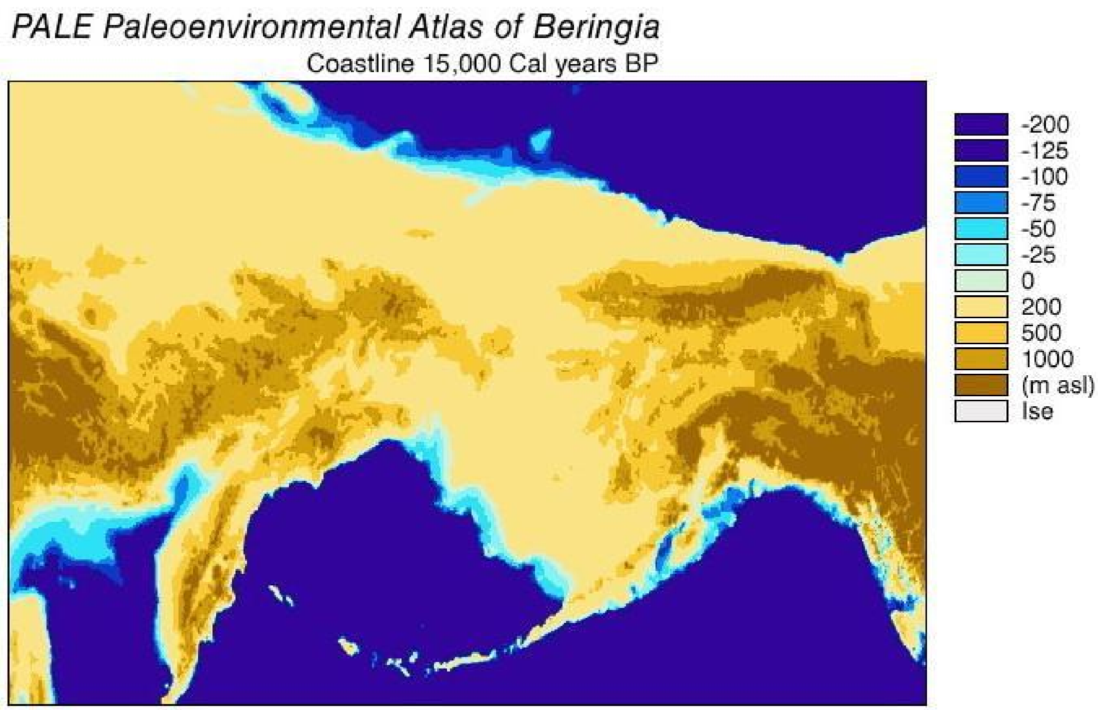

Figure 2. Alaska's exposed land bridge known as "Beringia" circa 15,000 BP (NOAA National Centers for Environmental Information, http://www.ncdc.noaa.gov/paleo/parcs/atlas/beringia/lbridge.html

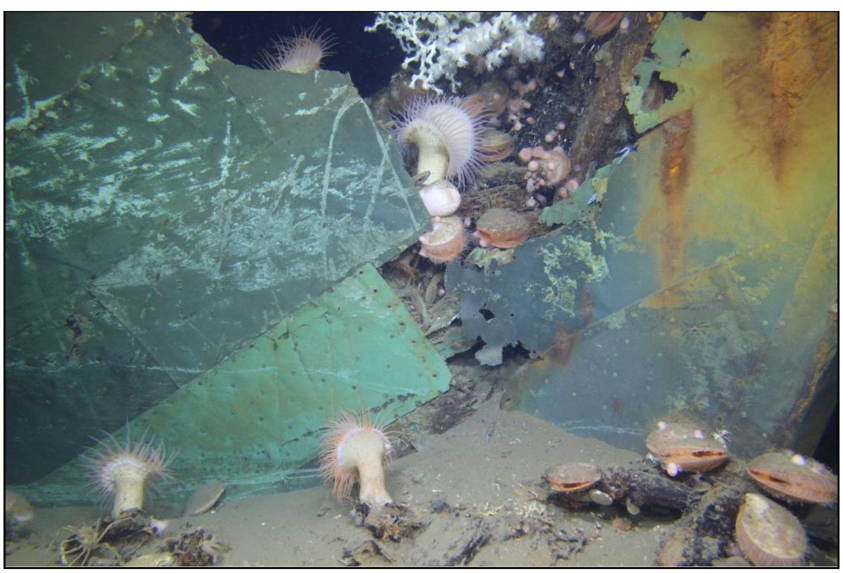

Figure 3. Located in approximately 600 m (~2,000 ft.) of water off the coast of Louisiana, the 19th century wooden-hulled, copper-sheathed Ewing Bank Shipwreck provides habitat for a diverse community of microorganisms and macrofauna in the northern Gulf of Mexico. Photo by Oceaneering's Global Explorer ROV. Image courtesy of the GOM-SCHEMA Project, BOEM.

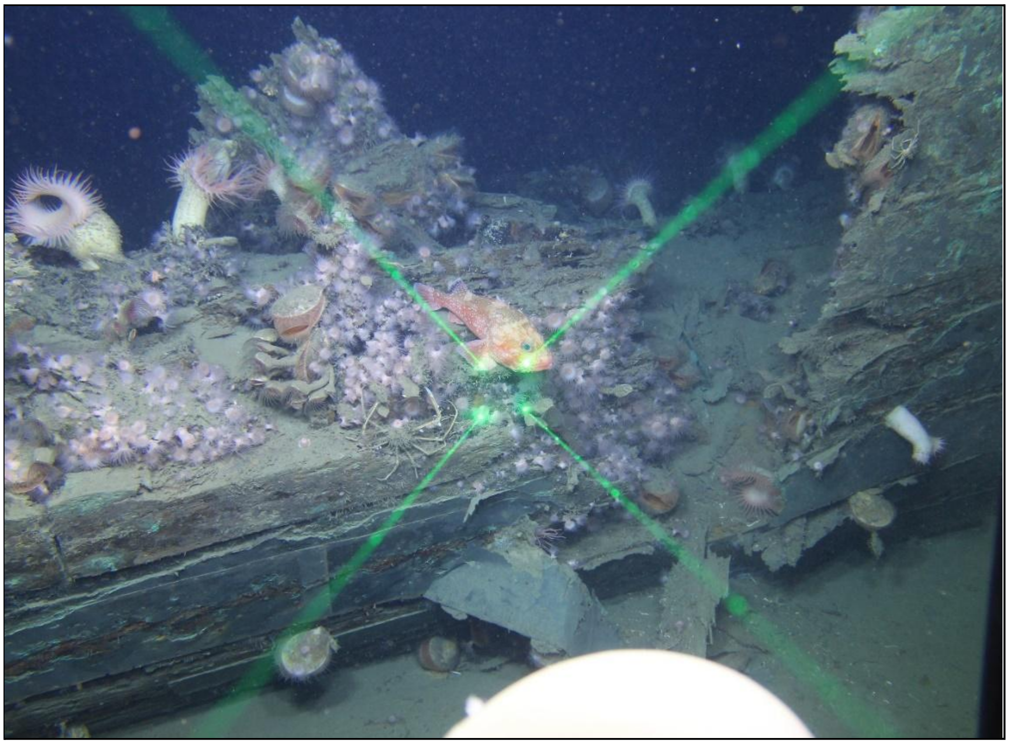

Figure 4. Evidence of damage to the Viosca Knoll Shipwreck from anchoring activities during the construction of a nearby oil and gas platform off the coast of Louisiana. One anchor chain sliced through the wooden hull (area to the right of green laser scales) of this previously undiscovered shipwreck causing permanent, irreparable damage. Image courtesy of the GOM-SCHEMA Project, BOEM.

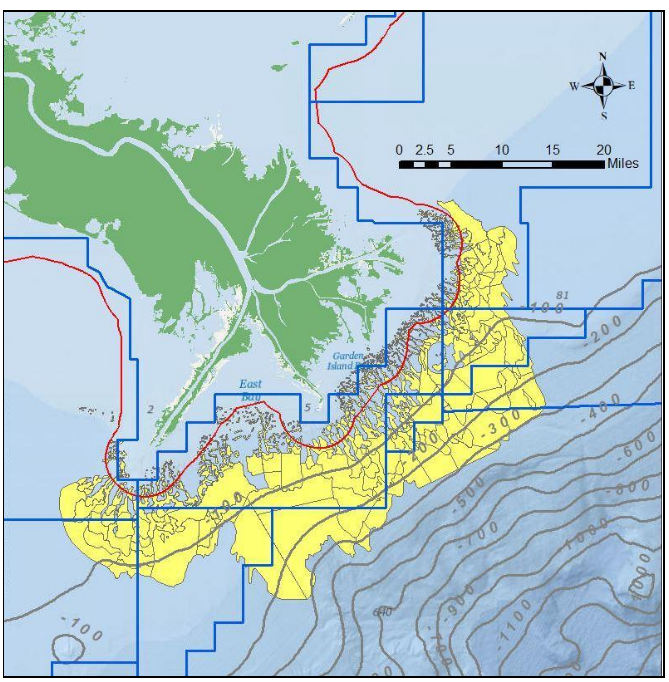

Figure 5. Map of the Mississippi River Delta Front area off the coast of Louisiana prone to submarine mudslides (in yellow), showing bathymetry (in meters). Map image digitized from Coleman et al. (1980).

Appendix C - cultural heritage white paper

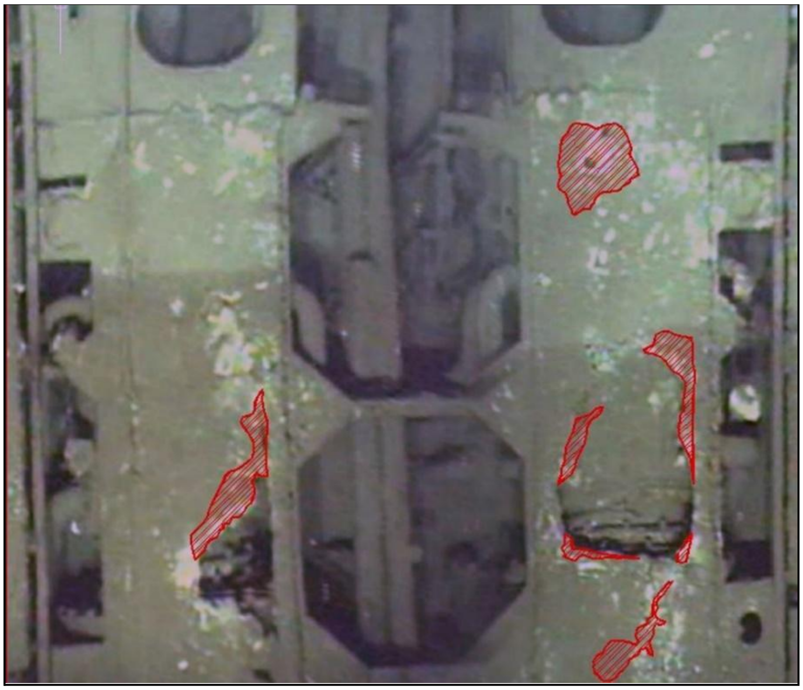

Figure 6. 2003 photo of the German U-boat U-166*'s deck overlaid with red indicating the extent of corrosion observed in 2013. Expansion of existing areas of corrosion accelerated in the three years after the 2010* Deepwater Horizon *oil spill in the Gulf of Mexico as compared to the rate observed in imagery collected during the nine years prior to the spill. Image courtesy of the GOM-SCHEMA Project, BOEM.*

IWG-OEC Marine Resources Subgroup

Co-leads: Jeremy Potter (BOEM) and Amy Gartman (USGS)
Members: Tom Bjerstedt (BOEM), Dave Butterfield (NOAA), Shannon Cofield (BOEM), Curry Hagerty (Navy), Jolie Harrison (NOAA), Kristen Hart (USGS), Kevin Johnson (NSF), Christina Kellogg (USGS), Jennifer Miselis (USGS), Katherine Morrice (DOE), James Morris (NOAA), Michael Parke (NOAA), Ninette Sadusky (Navy), Carrie Schmaus (DOE), Jay Singh (BOEM), Laura Strickler (NOAA), Cathy Tortorici (NOAA), Lisa Wickliffe (NOAA)

Introduction:

Despite economic and national security issues that increase national attention on the importance of marine resources, there remains a very limited understanding of many of these resources within the U.S. Exclusive Economic Zone (EEZ). Accelerating the exploration and characterization of marine resources aligns with comprehensive U.S. national defense strategies to safeguard specific resources and to protect U.S. marine and coastal critical infrastructure. Advances in ocean exploration improve federal attention to emergent national security concerns related to domestic food, valuable mineral, and energy supplies, maritime commerce, and climate resiliency. With dedicated focus and thoughtful implementation NOMEC can – and should – facilitate greater attention and understanding of the living and non-living resources within U.S. waters.

Appropriate sustainable management of living and non-living marine resources requires an understanding of the resources and the surrounding environment. Previous efforts to prioritize geographic areas for exploration and characterization largely focused on the surrounding environment. Past forums have only rarely discussed how to enhance the understanding of the actual resources. The primary exception was the 2020 Consortium for Ocean Leadership (COL) Pacific Priorities Workshop, which included an explicit Marine Resource theme and breakout group.

Following the COL Pacific Workshop, the NOMEC Council and IWG-OEC established a Marine Resources sub-group. However, there were no constraints or bounds put on the scope of the IWG-OEC Marine Resources sub-group. By default, the current sub-group scope encompasses any living and non-living 'resource' spanning habitats from 40 m to 1000s m water depth; including the water column, the seafloor or even 100s to 1000s of m below the seafloor.

During the initial IWG-OEC Marine Resources sub-group meeting, members quickly agreed that attempting to identify and meaningfully rank five geographic areas for exploration and characterization with such an expansive scope was not possible. Rather a brief resource-specific summary of the state of the knowledge and data gaps for each type was a more relevant contribution. The group elected to self-divide into individual Resource Teams. Most teams were comprised of only two or three members. Some members had specific expertise in the resource. Some had indirect expertise but a strong interest in the topic. Initial discussion and surveys resulted in seven discrete Resource Team topics which include: 1. Fisheries Habitat 2. Aquaculture 3. Renewable Energy 4. Critical Minerals, 5. Sand and Gravel, and 6. Natural Products.

Hydrocarbons – oil, gas, gas hydrates - were initially considered but ultimately excluded from the current prioritization exercise based on guidance from the NOMEC Council. This was because the types of operations required to understand hydrocarbon resources typically include deep-penetrating subsurface technologies and that are largely distinct from the other types of activities and information needs associated with mid-water and benthic living and non-living resources. Though hydrocarbons were excluded from this sub-group's prioritization, there are other reasons (e.g., climate change, seafloor hazards, sensitive biological communities) why hydrocarbons and/or their surrounding environment may be included by some of the other sub-groups. Hydrocarbon resources may be considered more by the

Marine Resources sub-group in the future based on additional guidance from the NOMEC Council and IWG-OEC co-chairs.

Each Resource Team documented their unique approach to the prioritization effort and identified a small number of priorities specific to their resource. The lens through which these priorities were identified varied for each team. For instance, critical marine minerals, sand and gravel, and natural products focused regionally on where the resource itself is known or expected to occur. This includes characterization needs for the resource itself, and – to a lesser degree - the surrounding environment. In contrast, fisheries habitat, aquaculture and renewable energy focused on characterizing the surrounding environment, rather than the resource itself.

Very broadly, data needs and technologies identified overlap between all groups and include water column chemistry, seafloor maps, photography, geologic, geochemical and biological data, obtainable through research vessels and deployable assets. Identified challenges include time and funding (universal), as well as correct sampling (natural products, critical marine minerals), better exploration technology (critical marine minerals) and coordinating multiple use areas to ensure ecological health (aquaculture). Summaries for each resource type follow.

In addition to the six teams, protected living resources (e.g., marine mammals, sea turtles) was determined to be an important resource category that was outside the scope of this exercise. Considerations related to protected living resources are incorporated as an appendix.

The approach, level of discussion, and confidence in the priorities areas varies greatly between teams. There was no attempt to reconcile priorities across Resource Teams. For some teams (fisheries habitat, aquaculture), the summary that follows is based on previous, more expansive, efforts and is somewhat comprehensive based on available data. For others, such efforts have not been attempted (marine natural products) or, despite attempts, are still severely data limited (critical marine minerals). As a result, we consider this to be a preliminary exercise that must be followed by robust and detailed dialogue including scientists and program managers in order to resolve a robust plan of work.

While all polygons provide valuable potential targets for exploration and characterization, substantial discussion with additional key experts, perhaps in the form of resource specific working groups, would be required to ensure that subsequent work has a meaningful impact on our direct understanding of marine resources in the U.S. EEZ. Without that dialogue, the geographic priorities exercise is unlikely to result in the most valuable data and information to inform prospective decision-making. Depending on how it is applied, it could inadvertently direct precious limited resources (e.g., funding, personnel) in a counterproductive manner.

At the end of the prioritization exercise, multiple sub-group members still had fundamental questions about the purpose and motivation for the effort. Some wondered if the exercise was done to explicitly inform extraction activities. Others asked how the group was expected to balance conservation. Co-leads offered their perspective that the sub-group's primary purpose was simply to facilitate better understanding of what resources are located in the EEZ and the data needed to understand these resources. That objective information is a prerequisite for making any informed resource management decisions – whether toward extraction or conservation. Pending additional guidance from the NOMEC Council and IWG-OEC co-chairs about the intended purpose of the sub-group, Marine Resource Sub-group members will provide recommendations for how to better address the topic moving forward.

1. Fisheries Habitat

Team lead: Michael Parke (michael.parke@noaa.gov) Collaborators: NMFS Office of Science and Technology and Office of Habitat Conservation

Scope and approach: Fisheries habitats are of interest for economic and national security interests, as well as intersecting interests regarding conservation, recreation, and indigenous uses. A major priority for the Department of Commerce is to lessen our dependence on imported marine food products and help sustain coastal communities. Strategies for achieving this goal include mapping and characterizing important marine habitats. In 2020, NOAA surveyed the regional science centers and management offices to identify the high, medium, and lower priority mapping needs for their respective regions. High priority habitat grids of 100 sq km area were identified as those that should be mapped/characterized as soon as possible, and preferably within 1-2 years. These are known habitats and potential habitats that are considered most important for recreational, subsistence, or commercial fishing needs and/or endangered species protection, and are in need of better mapping/exploration so that we can achieve a more complete understanding of the ecosystem processes critical to U.S. fisheries and the designation of future protected areas.

Geographic Priority Areas: This mapping exercise in 2020 did not attempt to prioritize across the geographic regions. Instead, each region was asked to place no more than 10% of their EEZ into the high priority mapping category. The maps provided graphically represent the marine areas considered high priority by the Alaska, Pacific Islands, West Coast, Northeast, mid-Atlantic, Southeast, Caribbean, and Gulf of Mexico regions. Each geographic region within the U.S. EEZ identified their primary and secondary justifications for needing better mapping in these areas and also identified the type and spatial resolution of map products that would be considered most useful. We note that many of the high-priority areas identified occur within Marine National Monuments, which does not preclude scientific research but may limit types of sampling and usually precludes commercial fishing activities.

What are the existing technologies that can currently support these priorities? What are the challenges to gathering data or getting what is needed to assess? How could these challenges potentially be overcome? Existing technologies include sea going vessels for bathymetric mapping and backscatter collection, biological and ocean water column sampling, and satellites/aerial platforms for surface and shallow subsurface characterization. Remotely Operated Vehicles (ROV), Autonomous Underwater Vehicles (AUV), moorings, floats, and LIDAR operations are available for sampling (biological, chemical and geological), detailed (sub-meter) mapping and seafloor photography, ocean currents, and transition zone characterizations. The biggest challenges in gathering relevant data for critical habitat are the enormous areas lacking data and the number of data sets that are needed, the seasonality of much oceanographic and biological data, the lack of understanding of fundamental requirements for multiple life stages of marine organisms, and variation in time and depth of most phenomena of interest. Lack of synoptic information at various depths may be the single largest mapping need. The other particular challenges are the rapid changes we are seeing in the marine environment due to climate variation, and the integration of data from multiple platforms, instruments, and databases.

2. Aquaculture

Team lead: James Morris (NOAA)

Scope and approach: Aquaculture focused on marine resource characterization needs that could support aquaculture development rather than the aquaculture industry itself. The practice of aquaculture is highly diverse, includes the cultivation of finfish, shellfish, and algae, and utilizes a wide variety of approaches including line culture, cage culture which can be both floating, suspended in the water column, and occur on or near the bottom.

Priority Geographic Areas: These priority areas were developed in consultation with the NMFS Regional Aquaculture Coordinators, industry, and utilized expertise within the NOAA [Coastal Aquaculture Siting and Sustainability] program. The following areas were identified: Alaska including the waters off of the

Aleutian Islands and in the Gulf of Alaska; the leeward side of Oahu and western side of the Big Island (Kona area) of the Hawaiian Islands (50 to 150 m); Guam and Saipan; the waters in Southern California (50 to 150 m depth), and some regions offshore of the Northeast US. These areas represent areas that could be suitable for aquaculture development pending further characterization.

What are the existing technologies that can currently support these priorities? What are the challenges to gathering data or getting what is needed to assess? How could these challenges potentially be overcome? Sustainable, long-term success for aquaculture is dependent upon the balance of ecological health and industry (e.g., wind energy, transportation, aquaculture) capacity. More, or improved, water column data (e.g. water quality, contaminants presence and loading, toxic algae, aragonite saturation state, nutrients) are needed to identify the most appropriate areas for various types of aquaculture. Improved mapping, exploration and characterization of the water column would support improvements in distribution models (larval dispersion and particle distribution), which are driven by hydrodynamic forcing factors within the water column and can be altered by benthic features such as shoals and ledges, etc. Improved data (higher spatiotemporal resolution) would support further refinement and evaluation of areas prime for potential aquaculture development. incorporation of point source and non-point source offshore inputs (e.g., potential contaminants, pathogens, and nutrient loading) would aid in the determination of the best aquaculture type and how and when aquaculture can be used for production of seafood for human consumption, or nutrient bioextraction. Other water quality parameters, such as bacterial loading and type, and dispersion within the water column would increase confidence in aquaculture siting and planning for long-term sustainable operations. Natural hydrocarbon seeps, the state of decades old unexploded ordnance, and the unknown positioning of many shipwrecks after years of episodic storms are issues that may impact the water column and can be better characterized through data collection efforts. The main challenge to gathering data is the large amount of data needed, and the broad areas over which it is needed.

References: https://deepseacoraldata.noaa.gov/; https://www.fisheries.noaa.gov/inport/item/55359

3. Renewable Energy

Co leads: Katie Morrice, Katherine.Morrice@ee.doe.gov, U.S. Department of Energy, Water Power Technologies Office and Jeremy Potter, Jeremy.Potter@boem.gov, Bureau of Ocean Energy Management, Pacific Region

Importance: Offshore wind and marine energy (e.g., wave, tidal, current, and thermal gradients) are abundant clean energy resources that have significant potential. The technical resource potential of U.S. offshore wind and marine energy is more than double the country's current electricity use. Of the two renewable resources, offshore wind is a nearer-term priority for exploration and characterization; however, interest in marine renewable energy for grid and non-grid applications is growing (see the Powering the Blue Economy™ report). Interagency ocean exploration and habitat characterization activities near sites of potential renewable energy development are already underway, but more needs to be done.

Scope and Approach: While priority areas for most marine resources (e.g., critical minerals, natural products, and fisheries habitat) focus on the exploration and characterization of a given resource, priorities for renewable energy consider regions where environmental characterization is needed to inform potential renewable energy development. Offshore wind (OSW) development is rapidly expanding along the Atlantic coast of the United States; however, almost all prospective development involves fixed-bottom wind turbines that are confined to shallower depths up to 50m, thereby precluding those regions from consideration. Similarly, tidal energy devices are typically deployed at shallower depths and areas closer to shore; however, wave and ocean current energy devices and ocean thermal energy conversion applications are well suited for deeper environments. With the emphasis on OSW and near-term applications, the priority areas reflect regions of interest for OSW and wave energy primarily in the Pacific. Preliminary discussions are ongoing about the potential for OSW in the Gulf of Mexico.

Priority Areas: The priority areas identified are informed by the discussion above and focus on deeper regions offshore. On the Atlantic coast, there are portions of lease areas off the coast of Massachusetts that are of interest for characterization activities but an explicit polygon is not currently available. The west coast of the U. S. and Hawaii are potential locations for OSW and wave energy. The relatively narrow shelf, steep continental slope, and deep water off the west coast of the U. S. and Hawaii, necessitate floating platforms for offshore wind turbines that are secured to the seafloor using massive anchors at depths up to 1000 m. Wave energy systems also require anchors to secure devices to the seafloor.

There are no existing OSW leases off the west coast or Hawaii. However, there are several areas under consideration for potential future leasing, including two locations off Oahu, Hawaii; two off Morro Bay, Central California; and one off Eureka in northern California. BOEM and the State of Oregon recently restarted discussions to determine the level of interest in potential OSW development off Oregon. There is one marine energy lease in federal waters off of Newport, Oregon that was issued in February 2021 to Oregon State University for the PacWave South Project, the first commercial-scale, utility-grid connected wave energy test site.

Common data needs and existing technologies to support these needs: Exploration and characterization activities that are of interest to offshore renewable energy include identifying sensitive benthic communities in the area, seafloor geology, sediment characteristics, and potential geohazards that need to be considered. There is substantial overlap in the data/information and technology needs with other sub-groups. Relevant technologies include AUVs, ROVs, multibeam and side-scan sonar, video and photographic surveys, and research vessels.

Partners or organizations that may be interested in these areas: BOEM, DOE, NOAA, Navy, state-based energy agencies, and various OSW and marine energy developers.

What are challenges to gathering data or getting what is needed to assess? How could these challenges be overcome? Cost of ship time for characterization efforts can be prohibitive. Relying on autonomous systems could help alleviate costs.

References:
https://www.energy.gov/eere/water/marine-and-hydrokinetic-resource-assessment-and-characterization; https://maps.nrel.gov/mhk-atlas/; https://maps.nrel.gov/mhk-atlas/; https://windexchange.energy.gov; https://www.boem.gov/renewable-energy/mapping-and-data/renewable-energy-gis-data.

4. Critical Marine Minerals

Team lead: Amy Gartman (agartman@usgs.gov) Collaborators: Dave Butterfield (NOAA), Shannon Cofield (BOEM), Kevin Johnson (NSF), Laura Strickler (NOAA), Michael Parke (NOAA)

Importance: Critical marine minerals are of interest for economic and national security interests, and raise intersecting interests regarding conservation. A full accounting of critical minerals within the U.S. would include those occurring in the oceans. Current efforts to identify and extract critical marine minerals are focused in international waters and within the EEZs of other nations. In U.S. waters, clear leasing or permitting frameworks do not exist for securing exclusive extraction rights to an exploration area and for commercializing seafloor mineral resources. From a national perspective, if the regulatory issues can be resolved, industry might increase their investment in characterizing these minerals in the U.S. EEZ and provide baseline information regarding associated ecosystems.

Manganese nodules (of interest for Ni, Cu, Mn, Co) have largest estimated tonnages globally, and it is suggested that manganese nodules would be the first mineral type to be exploited as exploration techniques for hydrothermal sulfide minerals (of interest for Cu, Zn, Au, Ag) and (Co-rich) ferromanganese crusts (of interest for Mn, Co, Ni, Cu, REY) are less well developed to date. In addition, terrestrial minerals may extend into the oceans along continental shelves, either directly or through weathering, and these coastal marine minerals are exploited globally; most notably, from a critical minerals perspective, for tin. We lack sufficient data to comment on any such "coastal" marine minerals that may occur below 40 m.

Scope and approach: While marine minerals occurrences are ubiquitous in the oceans, the areas with likely resource potential are much more limited. Our geographic priorities focus on areas of the U.S. EEZ which have the most resource potential for critical marine minerals. While characterizing the resource is the underlying objective of the "critical marine minerals" resource focused team, characterizing the surrounding environment is crucial to meeting the overall objective of identifying strategic priorities. Environmental characterization needs for marine minerals pertain both to any permitting of critical marine mineral extraction within a region for evaluation of impacts, as well as baseline monitoring of protected regions to evaluate environmental perturbations caused by extraction occurring in adjacent regions, whether or not those adjacent regions occur within the U.S. EEZ.

*Priority Areas***:** Our priority regions based on the above discussion include the deep abyssal plains and seamounts around Wake Island, as well as the deep abyssal plains and Magellan seamounts northeast of the Mariana arc. These regions are adjacent to one polymetallic nodule and four cobalt-rich ferromanganese crust exploration contracts issued by the International Seabed Authority (ISA), yet little scientific information, including mineral relevant information, exists within the U.S. EEZ (although a recent NOAA Ship *Okeanos Explorer* expedition collected crusts from the Wake region). A high probability of mineral occurrences is also true for other likely nodule bearing regions within the U.S. EEZ, including the abyssal plains around Jarvis Island, Kingman Reef and Palmyra Atoll, but there is little data from these areas.

We also considered regions of interest related to hydrothermal minerals, which include the Gorda Ridge (Escanaba trough), the Mariana arc and back-arc, and the Aleutian arc. The Escanaba trough and Mariana arc and back-arc regions have identified sources of high temperature hydrothermal fluid emissions and associated mineralization. Though coordinated scientific efforts previously occurred in both regions, neither the Escanaba trough nor anywhere in the Mariana arc or back-arc contains data sufficient for a resource or associated environmental assessment, or a scientific understanding of minerals and the environment. A major scientific exploration and characterization expedition to Escanaba is scheduled in 2022. Exploration in the Mariana region is also ongoing.

There is far less data collected in the Aleutian arc. No submarine hydrothermal locations within the U.S. EEZ portion of the Aleutian arc have been identified to date. As evidenced for the other hydrothermally active regions described above, acquiring sufficient information to understand the region will require a long-term plan of work. If the objective is to ascertain critical mineral resource potential and characterize the surrounding environment, then the need for long term investment is further emphasized. Initial mapping in 2022 will begin the search for submarine hydrothermal activity. In our discussions regarding hydrothermal minerals, the team discussed that the presence of hydrothermal activity does not indicate the presence of hydrothermal mineral deposits, and that active hydrothermal areas are considered to be a priority for protection. We noted that many of the regions listed above occur within Marine National Monuments, which does not preclude scientific research but may limit types of sampling and prevent any leasing activities.

Common data needs and existing technologies to support these needs: Data needs include physical samples of marine minerals and characterization of the associated environment. Technologies exist to resolve many of these data gaps, and need to be applied in the regions of interest. Sea going vessels for bathymetric mapping and backscatter collection, water column sampling, box coring, and to host remotely operated and autonomous assets. 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. Moorings are of use for environmental monitoring in regions subject to disturbance. Assessments of hydrothermal minerals would require drilling at regular intervals whereas typical characterization includes surface sampling. It is unclear if this type of activity is within the anticipated scope of the IWG-OEC. For characterization and assessments of crusts, development of technology to measure crust thickness *in situ* is recommended.

What are the challenges to gathering data or getting what is needed to assess? How could these challenges potentially be overcome? The biggest challenge in gathering critical marine minerals relevant data is the enormous areas lacking data and the number of data sets that are needed, comprising mineral data through environmental context. Lack of depth capable assets (for nodules) and lack of detection methods for inactive hydrothermal systems are further limitations. Further, correct sampling should be representative and include comprehensive and quality assured analytical work for all mineral types. Improving predictive mapping, improving a systems-based understanding of these mineral occurrences and their significance within the ocean system, and constraining the footprint of any environmental impacts associated with extraction are needed objectives. This can be accomplished through systematic efforts leveraging government, academic, and private scientists.

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5. Deep Sand and Gravel

Team lead: Shannon Cofield (shannon.cofield@boem.gov); Collaborators: Kristen Hart (USGS), Jennifer Miselis (USGS)

Importance: Offshore sand and gravel resources are highly sought-after by coastal communities and coastal industries for a variety of uses. Communities aim to protect coastal infrastructure, restore coastal environments, mitigate storm effects, and adapt to rising sea levels by rebuilding or renourishing beaches, dunes, and wetlands. Waves and winds redistribute sand, pebbles, or gravel along and across coasts. These natural sediment transport processes are amplified during storm events and large volumes of sediment can be redistributed to completely different coastal environments (e.g., from beach to shoreface; from dune to marsh via over wash). Climate change is predicted to increase storm strength and frequency in addition to coastal water levels (e.g., sea level rise) and it is anticipated that these changes will increase demand for sediment resources (Baird et al., 2018).

Scope and approach: Currently, beach renourishment leasing and dredging operations pursue offshore sand and gravel resources, known as borrow areas, near their replenishment area(s) in state waters and the near- Outer Continental Shelf (OCS) due to cost-savings. Due to the logistics of transporting offshore sand and gravel resources to the coastline, there is a rapid increase in cost for each mile sediment is transported from borrow area to emplacement area. Most ideal borrow areas typically lie in water depths <40m. However, the increased demand for these shallower resources has begun to exceed the rate at which they are able to naturally replenish their volumes. Diminishing shallower water resources necessitate identification and assessment of sand and gravel resources in water depths >40m. Additionally, offshore renewable energy, such as wind turbines, sometimes require gravel resources to support infrastructure. Therefore, the demand for exploration of deeper sand and gravel resources may not be driven solely by coastal sediment management priorities. Operating in deeper water >40 m may also minimize risk to threatened and endangered sea turtles. Habitat modeling efforts in the Gulf of Mexico (Fujisaki et al. 2020) showed several areas in deep water that may serve as suitable habitat, yet the density of turtles at such deeper sites is unknown. Although multiple factors likely influence habitat selection by these imperiled species, areas documented to be high-use zones are generally shallower than 100m (Hawkes et al. 2011, Shaver et al. 2013, Hart et al. 2020).

The regions in this study were selected based on their proximity to areas with the greatest resource needs. These are coastal regions identified by BOEM and NOAA that have a more urgent need for sand and gravel resources due to ongoing renourishment projects, rate of resource loss, or show a high probability for coastline vulnerability due to hurricane or storm events. The priority areas identified here are indirectly adjacent to regions with the greatest sediment needs.

Priority Areas Description: We selected 4 priority areas indirectly adjacent to regions with the greatest sand needs. We selected a location 114 mi off the west coast of south Florida. The region boasts a wide area on the continental shelf in water depths around 40 m that could contain sand and gravel resources. While this region is located a considerable distance offshore, the priority area spans a vast 31 mi wide by 200 mi long. Additionally, we selected a priority area 60 mi off the South Carolina coast. Along the U.S. southeast coast, the continental shelf tends to rapidly drop off from 40 m to 160 m, thus lacking surface area for resources to accumulate. We identified a 4 mi wide by 52 mi long priority area that could retain large volumes of sand and gravel resources. Additionally, we identified a 15 mi by 80 mi priority area located 25 mi offshore of the Florida panhandle. This region has the highest priority for investigation due to its large area and close proximity to regions with high need for sand and gravel resources. Finally, we identified a priority area on the north shelf of Alaska, which may have paleofluvial valleys with sand and/or gravel resources. Though adjacent to a relatively less populated area, this zone may be a long-term priority for energy infrastructure. It is unclear if there are sufficient sources of terrestrial sand and gravel to meet future needs.

Common data needs and existing technologies to support these needs: Bathymetry mapping can be achieved using interferometric or multibeam systems (or single beam, if applicable). Bathymetry data needs to conform to International Hydrographic Organization (IHO) Standards Special Order 1a/1b for water depths up to 100 m and adhere to NOAA Field Procedure Manuals, as applicable. To complete the exploration and characterization, other potential geophysical, geological, or environmental survey techniques are required including: side scan sonar or interferometric backscatter; sub-bottom profiler, chirp sonar, boomer, seismic, or equivalent electromechanical sources; magnetometer or gradiometer; vibracores, underwater still photography or videography; or acoustic sound source verification.

What are the challenges to gathering data or getting what is needed to assess? How could these challenges potentially be overcome? In general, surveys can be completed using vessel-based, off-the-shelf technologies, however, transfer of these technologies to ROVs, AUVs, or Autonomous Surface Vehicles (ASVs) may require development investments.

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6. Natural Products

Co-leads: Christina Kellogg, ckellogg@usgs.gov, USGS
Collaborators (including agency represented): Amy Wright (FAU-HBOI), Barry O'Keefe (NCI)

Importance: Exploration of natural products (compounds derived from sources such as plants, animals or microbes) has been a fundamental part of medicine and human health for centuries. As molecular and chemical technology have grown, the importance of novel discoveries now extends beyond medical drug development (e.g., cold-active enzymes for laundry detergents, glues developed from mussel adhesives). The economic interest includes possible development from multiple business sectors: pharmaceutical, cosmetic, manufacturing, industrial, agricultural, etc. In terms of conservation, uncovering novel natural products is encapsulated within understanding the biodiversity of the deep sea (with particular attention to invertebrates and microbes) and how best to manage it.

Scope and approach: The amount of novel biological diversity in the deep sea is large, and then the associated microbial diversity on top of that is even larger, so potential marine geographic targets for biomedically/biotechnologically relevant natural product resources could basically be THE OCEAN. Even areas that have been heavily characterized and sampled previously are still likely to have unexplored biota/microbiota. Having said that, we were asked to come up with priorities. Our collaborators provided information on areas that have been highly sampled for natural products to help order priorities. Previous *Okeanos Explorer*, *Nautilus*, and *Falkor* expeditions (back to 2001) were screened to identify any that specifically focused on bioprospecting/natural products and those areas were also ruled out as priorities. Areas of interest were identified by the contacted experts, mainly off U.S. Pacific Islands due to their lack of study compared to areas along the continental borders and that observed biodiversity on some of the limited expeditions. These areas were then examined to see if any of them overlapped areas that had not been bathymetrically mapped to high resolution, with the idea that high resolution mapping plus exploration/characterization would make best use of an expedition.

Priority Areas Description: Based on criteria described above, three priority target areas were identified; the EEZs around Wake Island (a 2016 *Okeanos Explorer* cruise showed lots of biological diversity); around Johnston Atoll, and around Jarvis Island. Secondary targets (areas that are of interest for natural products but have been heavily mapped) include around Guam, seamounts between Hawaiian islands and Midway, and the northern (Arctic) coast of Alaska. No ranking, since as stated initially, any of these areas (or others) could be valuable for natural products since this type of resource has not been pursued in many areas. If other teams/resource topics converge on different areas, there is a good chance they will be of interest for marine natural products even if outside the polygons that have been identified here.

Please list other partners or organizations that may also be interested in these areas:

https://www.grc.org/marine-natural-products-conference/2020/

*Common data needs and existing technologies to support these needs***:** Basic oceanographic data (depth, temperature, salinity), invertebrate species taxonomic identification and density/cover measurements; collections made in a way that preserves microbiological samples (minimized cross contamination) and with sufficient volume of invertebrates (500g to 1kg) for both chemical testing and microbial isolation. Relevant technologies are research vessels with ROVs/HOVs (Human Occupied Vehicles) and wet lab areas such as NOAA Ship *Okeanos Explorer*, E/V *Nautilus*, R/V *Falkor,* R/V *Atlantis*, and NOAA Ship *Ron Brown,* and others.

What are the challenges to gathering data or getting what is needed to assess? How could these challenges potentially be overcome? Correct sampling is needed. Although currently, invertebrate sampling occurs on the exploration ships during exploration/characterization expeditions, the way it is done is not suitable for natural products research. First, samples need to be collected in a way that minimizes microbial (bacterial) contamination, meaning individual samples go into individual containers that seal. Putting a bunch of things together in a biobox where they have physical contact or even share water can lead to cross contamination. Similarly, containers that do not seal exposed samples to different microbes as they pass through various water masses moving from depth to the surface. Simple PCV quivers with rubber stoppers have been effectively used to isolate individual samples for this type of work. Secondly, to do chemical surveys to detect interesting natural products, a volume of at minimum 100 g, but preferably more like 500 g to 1 kg is needed. Normally only small pieces (<5 g) of invertebrates are persevered for genetic analysis and the rest is used for taxonomic vouchers. Special preservation methods may also be needed. With some specific collection protocols, however, it would not be overly burdensome to accommodate this kind of work during regular exploration cruises in addition to dedicated natural products expeditions.

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Appendix I – Protected Living Resources

The Role of the NOAA Fisheries Protected Resources Program

Background

The NOAA Fisheries Protected Resources Program is participating in the Water Column and Mineral Resources subgroups to assist with environmental compliance issues as the subgroups identify specific exploration and characterization of priority areas. Protected species, including marine mammals, sea turtles, fish, and corals are important sentinels of ocean health. Changes in protected species distribution, habitat use, abundance, prey availability, or health condition that may occur as a result of the eventual actions of these subgroups are among the potential indicators of changes to the ocean environment. The NOAA Fisheries Protected Resources Program focuses on environmental compliance per Section 7 of the Endangered Species Act (ESA) and Sections 101(a)(5)(A&D) of the Marine Mammal Protection Act (MMPA) for specific geographies/actions taken by Federal agencies and applicants, which can include researchers like universities and private research institutions.

NOAA Fisheries Protected Resources Program Overview:

- The mission of the NOAA Fisheries Protected Resources Program is to protect, recover, and conserve protected species, such as marine mammals, sea turtles, fish, and corals, as well as their habitats.
- We execute these responsibilities through the authorities provided under the ESA and MMPA. NOAA Fisheries and the U.S. Fish and Wildlife Service share primary implementation responsibilities for these acts.

ESA Overview:

- NOAA Fisheries goals in implementing the ESA are to:
    - Conserve threatened and endangered species and their ecosystems.
    - Reduce threats so species recover to the point at which they no longer need the protections of the ESA.
    - Evaluate and authorize necessary activities that may affect ESA-listed species.
- NOAA Fisheries is currently responsible for 165 marine and anadromous species per the ESA.
- Under Section 7(a)(2) Federal agencies must consult with NOAA Fisheries when any project or action they authorize or take might affect an ESA-listed marine or anadromous species or its designated critical habitat. The consultation process can vary depending on the complexity of the project or action, and if "take" is expected, results in a biological opinion.

MMPA Overview:

- NOAA Fisheries goals in implementing the MMPA are to:
    - Protect and conserve marine mammals and their habitats.
        - prevent marine mammal species and population stocks from declining beyond the point where they cease to be significant functioning elements of the ecosystems of which they are a part.

        - investigate marine mammal health and respond to emergency events, including investigating unusual mortality events and their causes.
    - Maintain marine mammal populations for the benefit of the environment and the economy.
    - Evaluate and authorize impacts from necessary activities that may affect marine mammals.
- Our major responsibilities under the MMPA include:
    - Managing marine mammal bycatch (i.e., entanglement, hooking, entrapment) in fishing gear, including through the Take Reduction Program for commercial fisheries.
    - Developing stock assessment reports for all marine mammals under our jurisdiction in U.S. waters, which for strategic stocks, considers other factors that may be causing a decline or impeding recovery of the stock, including effects on marine mammal habitat and prey.
    - Evaluating requests for marine mammal incidental take authorizations and permits for research and other activities, and issuing authorizations and permits provided the necessary findings are made.
    - Coordinating effective responses to strandings, entanglements, vessel strikes and unusual mortality events.

Jurisdiction of the ESA/MMPA Consultation Process

It is important to note that NOAA Fisheries' jurisdiction under the ESA and MMPA applies up to actions which occur outside of U.S. territorial seas (12 nmi boundary - the high seas under the ESA) and outside of the U.S. EEZ. For ESA section 7 consultations, we are required to examine the effects of the action throughout the entire action area in making our jeopardy determination. However, we do not have authority under the ESA to authorize incidental take within the sovereign territory of another country. Therefore, an incidental take statement associated with a biological opinion does not cover incidental take of ESA-listed species (including marine mammals) in the territorial seas of foreign nations. Under the MMPA, only U.S. citizens may apply for incidental take authorizations and, similarly, these authorizations may not authorize take of marine mammals in the territorial seas of foreign nations.

Appendix C - seafloor hazards white paper

Interagency Working Group on Ocean Exploration and Characterization
National Ocean Exploration & Characterization Priorities in the U.S. EEZ

Subgroup: Seafloor Hazards
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Outside-subgroup collaborators;
Tom Parsons (USGS), Samuel Johnson (USGS), Jared Kluesner (USGS), James Conrad (USGS), Danny Brothers (USGS), Uri ten Brink (USGS)

Description of subgroup interests and disciplines represented:

The *Seafloor Hazards* subgroup is interested in regions and geological processes that generate pervasive and distal high-impact hazards, such as; large subduction zone and transform earthquakes, landslides and submarine volcanic eruptions, and the tsunamis they can generate. While all of the priority areas are high-hazard, many lack baseline exploratory data (Central/Eastern Aleutians), making it impossible to accurately assess the probability of each hazard occurring over a period of time and their potential devastating effect on people and property in terms of loss of life and economic cost (e.g. risk).

Several priority areas do have extensive baseline datasets (e.g. multibeam data coverage in Cascadia, California, Caribbean), but lack cohesive, systematic, and well controlled data collection (e.g. multibeam collected with a common instrument platform) necessary to characterize small-scale geologic features. Similarly, many of these "characterization" areas require repeated data collection campaigns to assess the evolving nature of geologic processes (landslide/fault development).

The subgroup represents Earth scientists with broad focuses in geology, geophysics, and specialties in renewable energy infrastructure/engineering, oceanography, seafloor mapping, geochemistry, marine geology, seismology, subduction-zone/volcano/earthquake hazards, as well as aquaculture.

Please list the themes/topics (e.g., critical minerals or wind energy for Marine Resources subgroup) that are of highest priority for your subgroup. These need not be ranked. (limit 200 words):

Earthquakes subductions zones and offshore crustal faults produce some of the world's largest earthquakes and trans-oceanic *tsunamis* affecting coastal areas thousands of kilometers away. Our understanding of their hazard is critically hampered by our lack of knowledge. Seafloor geodesy is an emerging field of study for improving our understanding of these features, and determining the frequency of these events is critical.

Submarine landslides are capable of generating damaging *tsunamis* and directly affecting vital seafloor infrastructure (e.g., Taylor oil spill in 2004; O'Reilly, 2020). Landslides are ubiquitous features on the seafloor throughout the entire U.S. EEZ, yet the conditions necessary for and frequency of seafloor failure remain poorly understood in comparison to other atmospheric and oceanic phenomena, e.g., hurricanes, loop current dynamics, etc.

Submarine volcanic eruptions can occur in remote areas where typical on-land monitoring may be sparse and knowledge of vent locations and eruption histories are often incomplete or unknown. The highest priority is the identification of unexplored submarine volcanic vents in many parts of the Aleutian and Izu-Bonin-Mariana volcanic arcs (Tepp et al., 2019) and developing an understanding of their eruptive history and potential future hazard (Newhall and Dzurisin, 1988; Acocella et al., 2015).

Priority Geographic Areas: (*see SeaSketch for Priority Area bounds*)

Appendix C - seafloor hazards white paper

Description of Geographic Priority Areas (maximum of five (5), in ranked order):

Priority Area 1: *Cascadia Subduction Zone Frontal Thrust and Splay Faults* (**Characterization**)

Subduction zones host the world's largest, most destructive earthquakes and tsunamis. 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. Recent great (M>8) subduction zone earthquakes in Japan and elsewhere have demonstrated the significant earthquake, tsunami, and landslide hazards posed by coseismic or triggered deformation of the upper plate, particularly offshore and above shallow megathrusts. For example, tsunamis produced by splay fault rupture and submarine landslide generation during the 1964 Alaska earthquake (Parsons et al., 2014; Haeussler et al., 2015) and shallow megathrust rupture in the 2011 Tohoku-Oki (Japan) earthquake (e.g. Sun et al., 2017) were responsible for the majority of fatalities resulting from each earthquake. Two important lessons learned in Japan for improving earthquake and tsunami hazard characterization were the need for: 1) pre-event systematic high-resolution bathymetric data along the frontal thrust and potential splay faults, and 2) near-trench seafloor geodetic monumentation (Wang et al., 2018). Comparison of high-resolution multibeam bathymetry collected before and after the Tohoku-Oki earthquake showed that the fault ruptured to the seafloor at the deformation front (Sun et al., 2017), something previously thought impossible. The seafloor uplift was the primary cause of the devastating tsunami that claimed lives and the meltdown of the Fukushima Daiichi Nuclear Power Plant. An earthquake of similar magnitude struck the Pacific Northwest in January of 1700, causing both a local and transpacific tsunami. Two fundamental parameters for characterizing earthquake and tsunami hazard In Cascadia, the down-dip extent of locking and predominant megathrust rupture mode (buried, trench-breaching, splay-fault rupture), are largely unknown (e.g Wang and Trehu, 2016) and limit our ability to prepare for inevitable future events. While this priority area is primarily a characterization target, the systematic mapping effort proposed is also an exploration target for deepwater seeps and coral habitat. There are abundant opportunities to leverage resources and existing and planned scientific efforts in this region to expand the impact well beyond hazard exploration and characterization.

Priority Area 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 two high priority areas for assessing subduction zone driven earthquake and tsunami hazards:

Islands of Four Mountains (IFM) contains Mount Cleveland, which is the most persistently active volcano in North America over the last 20 years. Recent studies suggest that a previously unrecognized caldera or perhaps multiple calderas may be present in the IFM (Power et al., 2021) but available data do not allow us to confidently confirm the size, eruptive history, or evaluate the potential for future eruptions. This caldera has a possible size of 500 km^2, which would make it the largest known caldera in the Aleutian. Exploration data is needed to identify the eruptive history, extent, and size of this possible magmatic system as well as evaluate the possibility for future eruptive activity.

Bogoslof Island is the summit of a largely submarine stratovolcano located `105 km northwest of the city of Unalaska, Alaska, which is home to the Dutch Harbor fishing port, the busiest in the U.S. The most recent eruption in 2016-2017 generated at least 70 separate explosive events that produced ash clouds that rose to altitudes of 39,000' and interrupted air traffic on the North Pacific Air Routes (NOPAC) for months, despite most of the eruptions initiating under water (Coombs et al., 2019). Little is known about the configuration of the subsea portions of Bogoslof volcano. Exploration data is needed to identify the possible location of satellite vents, areas that may be susceptible to landslides, and similar features that would assist with identifying hazards associated with this highly active volcano.

Shumagin Islands Slope Area is a region of the Aleutian Trench where there is no significant strain accumulation along the megathrust, as indicated by land-based geodesy. Although one of two large (M7.8) earthquakes in 2020 was near, but adjacent to, the region of little strain accumulation, there remains significant questions as to how, why, where, and for how long this region has acted this way. Nowhere else on Earth is like this, and this is particularly remarkable as the adjacent parts of the megathrust are fully locked.

Unimak Island Area was the epicenter of **t**he 1946 M7.4 earthquake, which while relatively small by Alaskan megathrust standards, produced a large tsunami that had an outsized local runup elevation of 42 m at Scotch Cap, Alaska, wiping out a lighthouse and the people inside. The tsunami impacted Hawaii and killed 157 people, and was eventually detected in Antarctica. The cause for this large tsunami has been enigmatic. Okal and Hébert (2007) argued that the tsunami was caused by a large local underwater landslide to produce the local tsunami, but there was also slow slip near the trench to produce the transoceanic tsunami. Von Huene et al. (2014) identified a feature, Lone Knoll, which lies on the eastern end of the Aleutian Terrace, that may be a landslide block that produced the tsunami. Active seeps have been found on Gloria images of the region, and this area may present opportunities to examine accretionary prism hydrogeology and vent biota.

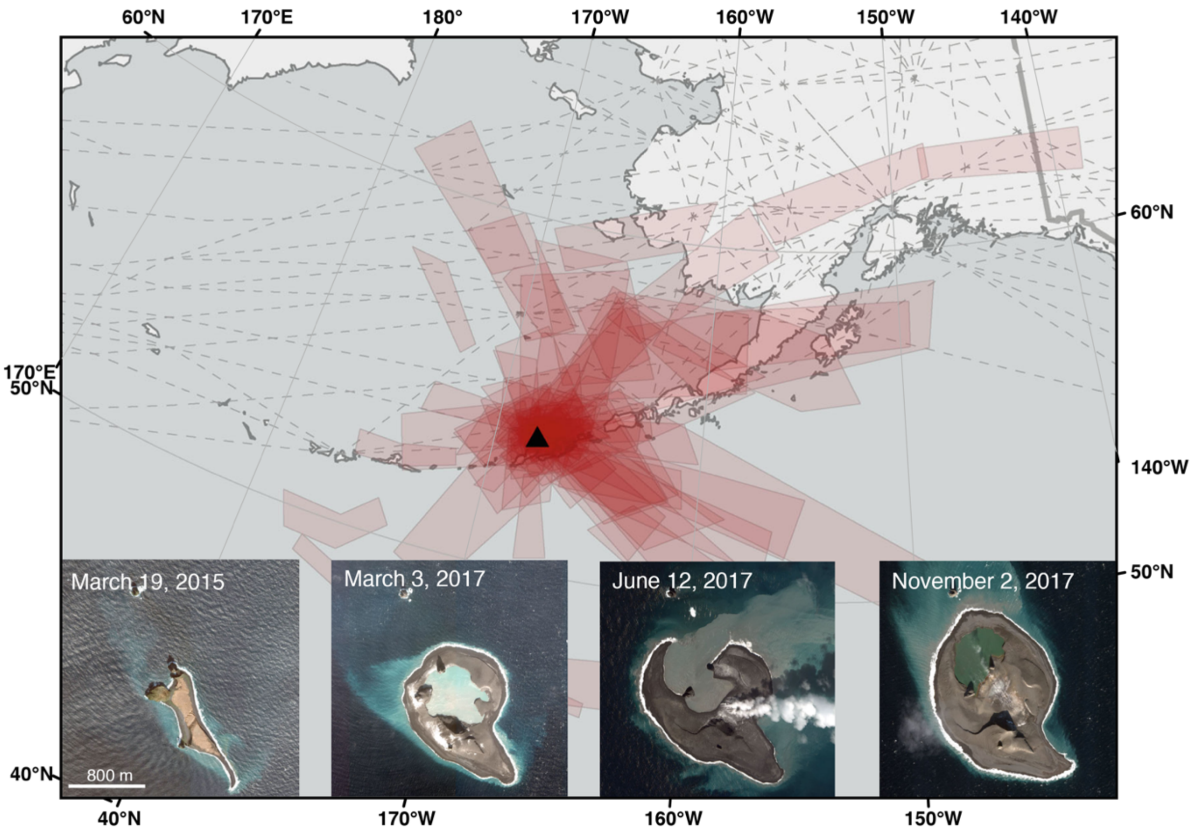

Figure 1: Map of the North Pacific showing discrete areas of airborne volcanic ash (in red) reported by the Anchorage Volcanic Ash Advisory Center (VAAC) based on satellite imagery, pilot reports, eye-witness accounts, and other data, for the time period December 2016 through August 2017. Over the course of the 2016–2017 eruption of Bogoslof volcano the Anchorage VAAC released more than 100 Volcano Ash Advisories, most of which included 24 h forecasts about likely plume trajectories and dispersion rates. Dashed lines show fixed high-level air routes in the region. (Insets) Select Worldview satellite images of Bogoslof from before, during, and after the 2016–2017 eruption. Worldview data provided under the Digital Globe NextView License. Figure modified from Coombs et al. (2019)

Priority 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. While this priority area is listed as an exploration target, this is due to the lack of any baseline data. Detailed characterization of this area would also prove invaluable. This area is near the population and infrastructure center of Alaska. The onland 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. There is no turbidite record of megathrust earthquakes in Alaska anywhere. This region has physiographic characteristics that make it one of the most likely to capture a turbidite paleoseismic record along the entire Alaskan margin. It is distal to Last Glacial Maximum glaciers, there is a good supply of sediment but not too close to the source, there is a range of slope angles, there are a number of possible impounding structures and associated basins. Sampling these basins could allow a turbidite record of earthquakes to be developed, and it could be compared to both coastal paleoseismology and lacustrine records already developed. This could provide a breakthrough in developing a long earthquake history for Alaska.

Southwest of Montague Island. A classic megathrust splay fault system ruptured on Montague in the 1964 earthquake. This has been traced offshore to the Junken trough region, but its extent to the SW is unknown, or if additional traces exist to the south. This fault has been consistently hypothesized to have produced one of the large tsunamis that impacted the town of Seward in the 1964 earthquake. The Junken Trough region is the target for proposed IODP drilling. A pre-proposal was approved and a full propsal will be developed.

Middleton Island. There was fault rupture beneath this island in the 1964 earthquake as well as interseismic uplift. We need to understand the nature and extent of deformation trenchward of this island to evaluate the hazard for the region. There is new information indicating there may be seeps associated with active faults in this region.

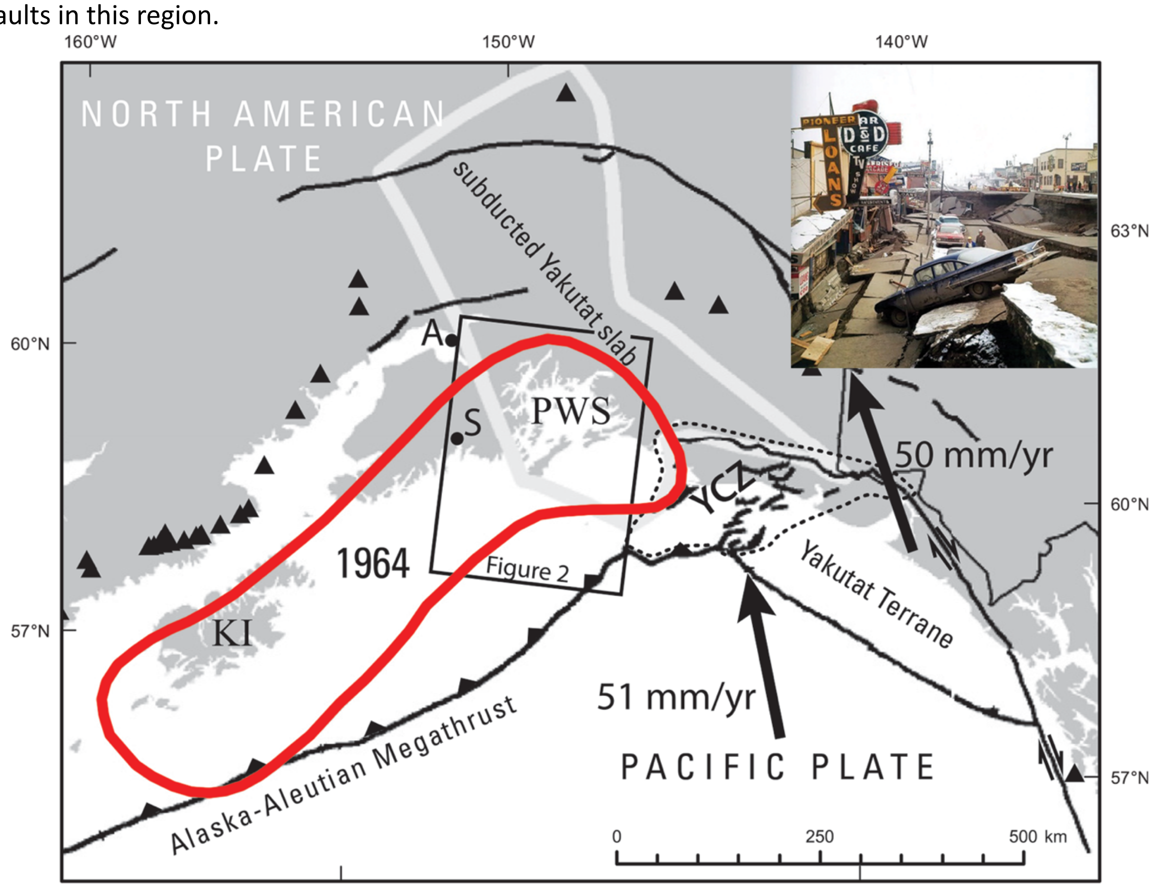

Figure 2: Map of tectonic setting of south-central Alaska. The rupture area of the 1964 earthquake is shown with the thick red line and 1964 label. Triangles show locations of volcanoes. Major active faults from the compilation of Plafker et al. (1994). Labels: Prince William Sound, PWS; Kodiak Island, KI; Seward, S; Anchorage, A. Dotted line surrounds the leading edge of the Yakutat collision zone (or Saint Elias orogen), labeled YCZ. (Inset)

Photograph of destruction in Anchorage caused by the 1964 earthquake. Figure modified from Haeussler et al. (2015).

Priority Area 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 in the region are:

Northern Channel Islands Fault System. The oblique-slip fault system represents a significant fault and tsunami hazard to southern CA population centers. In particular, little is known about the interaction between the eastern terminus of this fault system and active faults in Santa Monica Basin (i.e. Palos Verdes, Compton, San Pedro Basin). Since much of the framework geophysical mapping has been done, this target has data needs that are more specific and therefore represents more of a **characterization target**.

Coronado Bank Fault. This fault represents a significant fault hazard to southern CA, particularly San Diego and southern LA county. This fault system connects to the Palos Verdes fault further north. Since much of the framework geophysical mapping has been done, this target has data needs that are more specific and therefore represents more of a **characterization target**.

Borderlands submarine landslide/tsunami hazards. Submarine landslides pose a significant, but poorly understood, hazard to heavily populated coastal southern CA. The distribution and age of submarine landslides and the associated local tsunami hazard remains unknown in some areas and incomplete in others. This particular target has significant MBES mapping gaps in the outer Continental Borderlands and is therefore both an ***exploration and characterization target***.

Priority Area 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 regions 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:

Subduction Zone. Faults within the Puerto Rico trench and on the outer rise are capable of generating high magnitude earthquakes. Slip rates on these faults and recurrence times of significant earthquakes are unknown at this time. Tsunami deposits on Anegada and St. Thomas in the Virgin Islands are modeled to be the results of a M8.2-M8.45 earthquake in either the trench (thrust) or the outer rise (normal).

Crustal Faults. The recent 2020-2021 SW Puerto Rico earthquake sequence has revealed a hitherto unknown region of complex fault interaction (offshore and crossing the land-sea boundary) that has resulted in high-magnitude seismicity, damage to populations centers and coastal subsidence (first-hand accounts and inSar). Well-known historical crustal earthquakes accompanied by devastating tsunamis have occurred in the Virgin Islands (1867) and western Puerto Rico (1918).

Backarc thrust zone. Muertos thrust belt south of Puerto Rico and the Dominican Republic is similar to the Northern Panama Deformation Belt (NPDB), the Flores (Indonesia) back arc, and the eastern Vanuatu backarc, three regions in which magnitude 7.5-8.0 occurred during the 1990s. Earthquakes in these regions were accompanied by devastating tsunamis.

Submarine Landslides and tsunamis. Puerto Rico and the Virgin Islands have been impacted by numerous tsunamis as recorded in the geologic record and modern observational period. Tsunami sources are both far-field (eastern Atlantic) and local (trench, crustal faults and likely landslides). Numerous target areas for tsunami generation, including mapped landslides, fault surface traces, and potential onshore-offshore fault connections have yet to be studied in any detail

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Hurricane-driven coastal, near-shore and offshore change. There is documented evidence of significant impact to the reefs and other shallow water zones around the islands, with transport of material from shallow to deep waters. The impact of extensive sediment transport events on reef and deepwater environments is poorly known and the effect on offshore and coastal infrastructure, commerce, and populations is poorly realized.

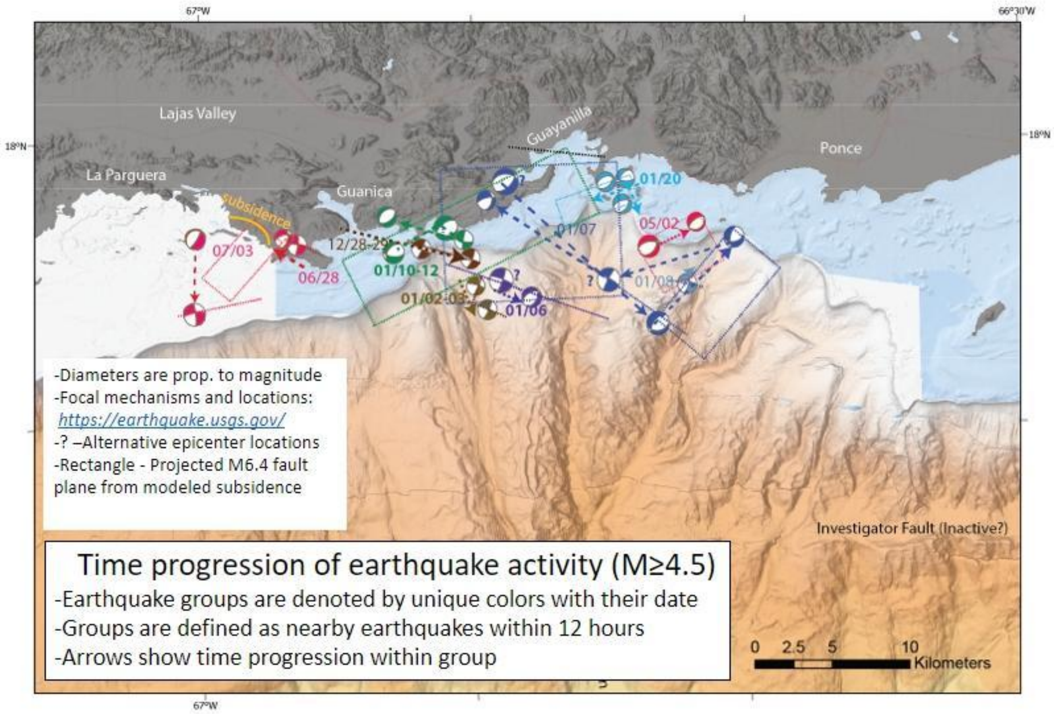

Figure 3: Earthquake activity (> M4.5) along the southwest coast of Puerto Rico as part of the ongoing seismic sequence which began at the end of December 2019.

Provide a list or brief description of the data needed within each priority area:

All priority areas require ship-based multibeam (10-20 m scale), backscatter, water column, and sub-bottom.

		ROV	HiRes mapping[1]	MCS (spark)[2]	MCS (airgun)[2]	Grav, Mag[3]	Core[4]	Grab[5]	Repeat MBES	Other
1	Cascadia	✓	✓	✓		✓	✓		✓	GNSS[6]
2	Island of Four Mountains					✓	✓			CTD
	Bogoslof Volcano	✓				✓	✓	✓		CTD
	Unimak/Shumagin Slopes	✓	✓	✓			✓			GNSS[6]
3	Eastern Alaska	✓	✓	✓			✓			GNSS[6]
4	CA Continental Borderland	✓	✓	✓		✓	✓			
5	Northeast Caribbean	✓	✓	✓	✓		✓	✓	✓	GNSS[6]

[1]**AUV/ROV mapping** – cm-to-m scale bathymetry, backscatter, water-column, sub-bottom imaging, photographs
[2]**MCS** – Multi-channel seismic reflection (sparker or airgun)
[3]**Grav/Mag** – shipped based gravity and magnetics
[4]**Core** – ship-based sediment coring (piston/vibracores/gravity/multi-coring)
[5]**Grab** – an ROV-based in-situ geological sample
[6]**GNSS** – seafloor GNSS/GPS-Acoustics
See Appendix 1.1 for additional information

Describe relevance to national security, conservation, and/or the economy:

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Earthquake and tsunami hazards are significant around the U.S. EEZ, and better characterizing their hazard will help protect life, property, and infrastructure of coastal communities, including numerous Tribal communities. In many areas, most of the population lives on the coast, with almost all U.S. communities are heavily reliant on coastal infrastructure and offshore resources (e.g., fisheries, oil and gas). In Alaska and the NE Caribbean, almost all supplies arrive or are exported via seaborne transport. The Pacific Northwest, southern California, and Alaska are home to numerous military installations that are in areas at risk from the hazards mentioned above.

Airborne volcanic ash represents an extreme hazard to the operation of aircraft and has caused hundreds of millions of dollars in damage to aircraft and can severely disrupt air traffic over broad areas of the country. Most subsea volcanoes in the US are located in the Aleutian and Izu-Bonin-Marianas volcanic arcs and are distributed under the north Pacific great circle aircraft routes (NOPAC) between North America and Asia that are traversed by more than 50,000 people each day as well as numerous cargo aircraft (Ewert et al., 2018).

From your perspective, what makes each priority area unique?

Priority Area 1: (1) Abundant framework mapping data makes higher fidelity/focused characterization studies possible. (2) Existing and planned regional efforts (NSF, USGS, EXPRESS, MBARI, BOEM) provide opportunity to expand the impact well beyond hazard exploration and characterization

Priority Area 2: (1) IFM - Large, caldera forming eruptions (CFEs) are one of the most transformative natural hazards that can have worldwide impacts (Plag et al. 2015). Over the last 10,000 years CFEs have been responsible for major climate changes resulting in world-wide famines, pandemics (Oppenheimer 2011), and political disruption (McConnell et al., 2020). (2) Bogoslof – Demonstrated impact on global air traffic.

Priority Area 3: (1) World class location for studying subduction zone processes, (2) Variable slip behavior along the length of the subduction zone with priority areas seen as those having high potential for breakthrough observations to understand the earthquake cycle, strain accumulation and release in subduction zones and tsunami generation, (3) Success is virtually assured as pioneering observations and measurements will be made.

Priority Area 4: (1) The wealth of existing data enables detailed high-level hazard characterization. (2) Proximity to large populations centers (high risk). (3) Ease of access by large vessels (close to ports).

Priority Area 5: (1) The Puerto Rico trench is the deepest point in the Atlantic Ocean and one of the deepest regions on the planet. (2) In addition to the ever-present threat of several natural hazards, the region has only been minimally explored and characterized. (3) Because of the population and infrastructure density along the shoreline, this region is more vulnerable to the effects of natural hazards relative to other U.S. margins.

Please list other partners or organizations that may also be interested in these areas:

(superscript numbers refer to priority numbers)

Communities, businesses, local/region/state governments[all]
NOAA (PMEL, OCS, NMFS, NWS)[all]
Academic Institutions (UW, UO, OSU, HSU, WWU, MBARI,etc.)[1,2,4]
Alaska (Fish and Game, Geological and Geophysical Surveys)[2,3]
Southern California Earthquake Center[4]
U.S. Central Command[5]
NSF(SZ4D, etc.)[all]
USGS (Natural Hazards Mission Area)[all]
BOEM/BSEE[1,2,3,4]
California Geological Survey[1,3]
NPS[4,5]
FWS[5]

What are the existing technologies that can currently support these priorities and what types of technology needs to be developed/improved upon to advance data collection/planning/processing techniques?

Existing – *see prior description of data needed*.

Need development/improvement;

- Seafloor geodetic techniques are rapidly developing and additional resources could be applied to accelerating research and development
- Autonomous MBES acquisition – further development of autonomous surface vehicles could more quickly map the sea bottom and meet the goals of Seabed 2030.
- Submarine cable observatory (Priority Area 5)

- Deep-water AUV/ROV mapping

What are the challenges to gathering data or getting what is needed to assess? How could these challenges potentially be overcome?

- Development of seafloor geodesy techniques to a mass scale in the US - there is a community of academic researchers pushing hard toward this goal.
- Area of interest may be near sensitive marine mammal habitats. Streamlined permitting required.
- Ship availability, financial resources for ship operations and trained personnel to conduct the work and synthesize the data. These challenges can be overcome through partnering and leveraging resources.
- Seafloor conditions not conducive to standard sampling techniques (reefs, carbonate banks, volcanoes) and extreme water depths beyond existing autonomous/remote platforms. New tools need to be developed (above)

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Appendix C - water column subgroup white paper

Interagency Working Group on Ocean Exploration and Characterization
National Ocean Exploration & Characterization Priorities in the U.S. EEZ
White Paper Submission Form

Subgroup: Water Column
Co-leads: Vecchione
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Collaborators (including agency represented):

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BOEM	Division Environmental Sciences	Michael Rasser
BOEM	Division of Environmental Assessment	Tamara Arzt
BSEE		Michelle (Shelly) Fitzgerald
FDA	Center for Food Safety and Applied Nutrition (CFSAN), Office of Food Safety	James Quentin Forrest
NASA	Ames Research Center	Craig Everroad
Navy	ONR	Scott Harper
NOAA	NOS/NCCOS/MSE	Chris Taylor
NOAA	NMFS/OPR/PCD	Jolie Harrison
NOAA	OAR/OER/STD	Adrienne Copeland
NOAA	OAR/OAP	Libby Jewett
NOAA	OAR/CPO	Ben DeAngelo
NOAA	NOS/IOOS/OD	Gabrielle Canonico
NOAA	OAR/PMEL/OERD	Susan Merle
NOAA	NMFS/OPR/ESAICD	Cathy Tortorici
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USGS	St. Petersburg Coastal and Marine Science Center	Kimberly Yates
USGS	Leetown Science Center	Aaron Aunins
USGS	Pacific Coastal and Marine Science Center	Pete Darnell

Description of subgroup interests and disciplines represented:

The background and general need for exploration and characterization of the water column have been reviewed and summarized by Netburn (2018). This was followed up by a 2020 workshop organized by the Consortium for Ocean Leadership (COL) for NOAA/OE to plan for upcoming field exploration in the Pacific, with explicit instructions to consider global needs. The COL workshop included a subgroup on water-column exploration, which assembled a set of recommendations.

For the current interagency workgroup, agency interests in exploring and characterizing the water column in US waters are both broad and diverse. These characteristics make summarizing and prioritizing the interests and recommendations in this and the following sections difficult. The interests expressed include aspects of the pelagic ecosystem itself as well as the water column as it relates to target benthic ecosystems. Stated interests ranged from water quality in coastal areas to geochemical plumes from offshore seeps. Measurements for all of the basic marine sciences (physical, chemical, biological and even geological oceanography) are needed. In addition to pure exploration and characterization (e.g., biodiversity discovery and mapping of protected resources), these measurements would support “blue economy” activities such as fisheries and aquaculture, resource mapping and extraction and environmental assessment and protection.

Appendix C - water column subgroup white paper

Agency participant interests from contact-list spreadsheet:

acoustic methods (passive and active) for WC characterization; sound impacts to marine mammals and fisheries
fisheries and fish habitat
policy, sound
Shellfish Growing Areas/Water Quality
Earth and Planetary Science
Exobiology
Physical Oceanography; modeling
Fish acoustics
Protected resources
Deep-sea water column, acoustics
Acidification
Climate change
Biodiversity
Seafloor mapping, geochemistry, marine geology, and microbiology, with specialization in submarine volcanoes and coastal margin methane seeps
Protected resources/ESA
Aquaculture
Biodiversity monitoring (traditional surveys and molecular genetic techniques like eDNA)
Oceanography, Paleooceanography
Oceanography, Ocean Acidification (etc.)
Population connectivity
acoustic methods

Themes/topics that are of highest priority:

Biological characterization of pelagic ecosystems, in terms of basic ecosystem structure and inferences about undisturbed function, is needed for all size fractions (microbes to whales). This includes dynamic processes such as active transport of biochemical properties and bentho-pelagic coupling.
Biology focused on applied problems is also needed as well. For example, occurrence and dynamics of harmful algae and microbes.

Physical oceanographic processes in the water column, both directly measured and inferred from measurements of physical properties are important in transport of both dissolved and suspended materials that are important in problems being addressed within agency missions. These materials range from sediment to pollutants and other chemicals. Acoustic characteristics of the water column are important to determine ambient levels that may be biologically important and to calculate acoustic propagation necessary to use a wide variety of tools necessary for detailed bathymetry and seafloor morphometry as well as exploration and characterization of the water column and the animals in it, benthic ecosystems and potential economic resources on the bottom and sub-bottom. Physical properties of the water column are also important in development of models to predict phenomena like storm systems that impact coasts and coastal ecosystems.

In addition to biochemical properties mentioned above, characterization of phenomena such as methane plumes, hypoxic and anoxic layers in the water column and near bottom, and acidification is needed to understand the roles of national waters in global cycles of chemistry that will affect both the blue economy and the planet in general.

Appendix C - water column subgroup white paper

Priority Geographic Areas:

In general, exploration and characterization of the water column is not as site-specific as are the other sub-group topics considered by this working group. With the exceptions of the area of Monterey Canyon and, recently, the northern Gulf of Mexico, the water column beyond the shelf break is so poorly explored that substantial progress can be made almost anywhere. The water column in coastal areas has received more attention.

Of course, agencies that are interested in a water-column component to support exploration/characterization of specific benthic targets or regional phenomena included geographic suggestions. A compilation of those suggestions is compiled geographically below, but without prioritization:

- Alaska (climate change)
  - Alaska North Slope
  - Bering Sea off Aleutian Islands
  - Aleutian arc
  - Eastern Gulf of Alaska
- Cascadia margin offshore WA, OR, and N CAL (from the shoreline to the base of the margin at the Cascadia subduction zone)
- Monterey Bay
- Southern California
- Hawaiian Islands
- Remote Pacific Islands
- Western Pacific Mariana arc and back-arc
- The Gulf Stream or other major ocean currents.
- Gulf of Mexico
  - Northern Gulf of Mexico continental shelf from Texas to west Florida shelf
  - Offshore Gulf of Mexico EEZ from continental slope out to the 3000m bathymetric contour
  - West Florida Shelf out to the 200m bathymetric contour.
- Southeast U.S. coastal zone from Dry Tortugas, Florida Keys to North Carolina out to the 500m bathymetric contour.
- All U.S. Coral Reefs with Florida Keys Reef Tract Prioritized from the Dry Tortugas, Florida Keys to offshore of approximately Port St. Lucie Florida, out to the 50m bathymetric contour
- Blake Plateau
- Northeastern Area (Massachusetts to Maine)

Another approach is to target types of areas rather than specific locations. Such suggestions include:

- Unexplored regions
- Areas undergoing significant current or expected future anthropogenic changes
- Biological hot spots
- Deep Scattering Layers (DSLs) – comparisons among basins/regions
- Contrasting environments that are in close proximity to each other
- Regions of potential commercial seafood aquaculture and wild harvest
  - NOAA Defined, Aquaculture Opportunity Areas (AOAs)
  - Northeast Area (Massachusetts to Maine)

Brief summary of the setting, what is known about the area, and rationale for exploration/characterization:

The FDA is interested in the characterization of the water column in areas associated with regions of potential commercial seafood aquaculture and wild harvest. The FDA is interested in identifying and characterizing potential seafood hazards that might need to be controlled to protect public health that might impact these areas. In general, one top priority is to focus on geographic areas consistent with Aquaculture Opportunity Areas (AOAs). Beyond AOAs, the FDA is specially interested in Southern CA and Northeast areas given existing industry interest to develop commercial aquaculture sites and harvest commercial seafood in these areas.

The Arctic and North Pacific is experiencing rapid regime shifts as a result of climate change. It's important to collect physical, chemical, and biological oceanographic data to document such changes. These changes can be captured from long-term passive and active acoustic datasets that show the characteristics and dynamics of geophysical, biological, and anthropogenic sounds.

The Gulf of Mexico area includes the northern Gulf of Mexico and West Florida Shelf, spans temperate to tropical climate zones, and siliciclastic to carbonate seafloor geology and associated interactions with the overlying water column. Water column chemistry in the Gulf of Mexico is highly influenced by terrestrial input from the largest watershed in the U.S. including 31 states, parts of Canada, Mexico and Cuba. 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. Persistent areas of hypoxia have been well-documented in the northern GOM subregion; however, much less in known regarding multi-stressor impacts including temperature, ocean and coastal acidification, and petroleum-based contaminants. There is a paucity of data on long and short-term trends and variability in ocean and coastal acidification and its impacts to GOM fisheries and associated species sensitivities. Water quality baselines are rapidly shifting due, in part, to increased frequency and intensity of major storms increasing freshwater and nutrient inflow to the GOM. While progress has been made regarding Blue Carbon studies, much remains to be understood in this region which is characterized by extensive seagrass, coastal marsh and wetland species that contribute to Blue Carbon and affected by coastal water quality. This region is also characterized by deep water coral reefs. Site specific, repeat data collection occurs through sparse fixed platform monitoring and periodic cruises. This area would benefit from a broader exploratory effort to examine connectivity within the region and to adjacent regions, particularly second tier physical/chemical measurements, first and second tier biological measurements.

West Florida Shelf out to the 200m bathymetric contour includes deep water coral reefs of Pulley Ridge, shellfisheries, extensive and persistent harmful algal blooms that threaten fisheries and socioeconomics of coastal populations.

Southeast U.S. coastal zone from Dry Tortugas, Florida Keys to North Carolina out to the 500m 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 as described above. The region includes the Florida Reef Tract which is the only living barrier reef in the continental U.S. (third largest in the world), several deep-water coral reefs, hard clam fisheries, and extensive Blue Carbon habitat. The region is impacted by many of the same stressors and data gaps as the GOM. Both the Southeast and GOM regions are increasingly threatened by greater frequency and magnitude of tropical storms exacerbated by climate change and degradation of coastal seafloor habitats that act as natural barriers from storm impacts due to declining coastal quality. Site specific, repeat data collection occurs through sparse fixed platform monitoring and periodic cruises.

All U.S. Coral Reefs (with Florida Keys Reef Tract Prioritized) from the Dry Tortugas, Florida Keys to offshore of approximately Port St. Lucie Florida, out to the 50m bathymetric contour: U.S. (and global) coral reefs are threatened by climate change including increasing seawater temperature, ocean and coastal acidification, water quality including eutrophication, and disease.

Monterey Bay is within the Monterey Bay National Marine Sanctuary which includes the Monterey Canyon allowing relatively close access to deep water allowing for the 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 studies can build on.

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 probably the least 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.

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Data needed within each priority area:

In general, see Table 1. Toolbox for Water Column Exploration measurement categories in Netburn (2018), prioritized into first and second tiers. Specific data needs submitted by the agencies for this exercise included:

- Harmful Algal Blooms (presence, species, concentrations, temporal dynamics)
- Current Profiles (direction, speed, min/max) – current modeled data is ~4km resolution, improved (meter-scale) resolution is needed for informing near-field depositional modeling for proposed aquaculture operations.
- Signatures of upwelling (e.g., nutrient concentrations/fluxes, dissolved oxygen concentrations) + ability to calibrate/validate models/forecasting
- Turbidity and light attenuation
- Oceanographic anomalies (e.g., cold water fronts + 'super chill events')
- Temperature, salinity, and current velocity through the water column – data on physical oceanography can help understand sound propagation, which can be used to build models to predict anthropogenic noise impacts.
- Measures of atmospheric methane at sea level.
- Long-term recording of ambient noise level and soundscape within the water column to document geophony (sounds from geophysical events, such as ice, precipitation, wave, and activities), biophony (sounds from animals), and anthrophony (anthropogenic sounds) characteristics and dynamics.
- Active acoustics to document schooling fish and plankton in the water column (e.g. deep scattering layer).
- Collection of water samples from targeted depths for eDNA. Concurrent sampling with tradition gear (e.g., nets) should be performed when possible for genetic reference and voucher specimens.

In all areas to be investigated, high spatial resolution (vertical and horizontal) and temporal resolution are needed to improve and expand currently existing modeling efforts that are built upon and validated with data from sparsely distributed (geographically and temporally) fixed platforms and ship-based cruises. For coastal zones, sub-kilometer horizontal resolution, vertical resolution dependent on water depth, and even higher temporal frequency measurements of many water quality parameters are needed

Relevance to national security, conservation, and/or the economy:

The water column is the largest, least explored biome on the planet, so there are many organisms yet to be discovered. We cannot conserve what we do not know is there. Additionally, from an economic perspective countries have begun to consider exploiting the mesopelagic micronekton resources. It is important to have a more accurate estimate of the density and abundance of these animals if they are going to be used for economic benefits. Current papers on acoustic and trawling methods report that the organisms in the mesopelagic are not accurately quantified.

Protecting seafood safety is vital to public health and therefore national security. Furthermore, assuring the safety of seafood harvested from U.S. waters not only contributes to our domestic economy but provides export opportunities. Development of the U.S. marine aquaculture sector is a national priority under the U.S. Department of Commerce Strategic Plan, further emphasized by the May 2020 Executive Order on Promoting Seafood Competitiveness. Appropriate siting of future aquaculture operations to minimize environmental and space use conflicts requires the availability of water column and other key data.

New acoustic propagation model is needed for the Arctic due to changing physical properties (temperature, salinity, current) in the Arctic and North Pacific resulting in changes in sound speed in the water column. This has important implication in national defense, and also marine resource conservation.

In regions characterized by mineral (e.g., oil/gas), food (fisheries), blue carbon, endangered and threatened species, low lying coastal populations (including several military bases) with threatened coastal habitats that protect them, multi-billion dollar economies are heavily dependent on coastal and marine resources. There are numerous federal and state protected areas within these regions that depend on accurate scientific data to develop short and long-term resource management and implementation plans.

Much of the US EEZ has not been mapped with simultaneous seafloor and acoustic water column data, especially in shallower water that is much more time-consuming to map. In general, methane seep sites and hydrothermal vents have been identified as possible energy sources (e.g., oil and gas), and sites hosting potential mineral or biological resources. Methane seeps have been listed as essential fisheries habitat off the west coast of the US. To fully understand these systems, they should be protected before ever being exploited so that their full value, potential, and uniqueness can be evaluated and appreciated. Only then can a rational conservation and management balance be achieved.

What makes each priority area unique?

The agency perspectives on priority areas are so diverse that describing unique attributes of each would greatly exceed the page limit for this exercise and would be redundant with the text above about setting.

Other partners or organizations that may also be interested in these areas:

I am not sure whether "other partners" means "other than federal agencies". Because this is an interagency workgroup, I have omitted federal agencies from the following suggestions suggested by participants.

- Interstate Shellfish Sanitation Conference (ISSC)
- State Shellfish Control Authorities (since any seafood product harvested in the EEZ will need to be landed and sold in a state of landing)
- coastal marine labs (universities)
- other state and local entities.
- Academic Institutions
  - Oregon State University
  - University of Washington
  - University of Hawaii
  - Stanford University's Hopkins Marine Station
  - University of Victoria Canada
- SCRIPPS Institution of Oceanography
- MBARI (Monterey Bay Aquarium Research Institute)
- Woods Hole Oceanographic Institute
- Virginia Institute of Marine Science
- Private partnership e.g., WHOI got a 30+ million-dollar private investment to understand twilight zone (100-1200m) processes.
- GNS Science New Zealand
- Ocean Exploration Trust
- Schmidt Ocean Institute
- Atlantic Deepwater Ecosystem Observation Network, UNH Ctr Coastal and Ocean Mapping

Existing technologies that can currently support these priorities and what types of technology needs to be developed/improved upon to advance data collection/planning/processing techniques?

It is important to develop efficient and effective characterization protocols by utilizing multiple complementary techniques and approaches (e.g., nets, acoustics, imaging, and in situ sensing) to execute multi-disciplinary programs. Genetic tools are well suited to inventorying biodiversity in the water column. Collection of voucher specimens coupled with genome skimming to recover barcode genes can help identify new species, provide material for population genetic analyses, identify early life stages where morphological characters are of limited utility, and contribute to reference databases for eDNA metabarcoding.

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For a basic list of existing technology, see Table 1. in Netburn (2018). Additional technology suggested by participants induces the following:

- Existing:
  - offshore imaging flow cytometers, etc.
  - Long-term acoustic monitoring system
  - Ships of opportunity for transect data
- Development:
  - advanced acoustic signal processing
  - unconventional platforms such as tagged marine mammals
  - ion-selective electrodes and sensors
  - glider (wave and underwater), float, and AUV data collection platforms
    - incorporate artificial intelligence, learning, and autonomous collaboration
    - increase data storage and uploading capabilities
    - Improve navigation, both horizontal and vertical
  - data collecting techniques, analyses, and visualizations to characterize volumes of water column, not just single casts or transects

Challenges to gathering data or getting what is needed to assess and potential solutions:

- Challenges include:
  - Individual agencies lack resources for comprehensive assessments
  - Time at sea, both ship-based and autonomous, requirements are extensive and expensive
  - Water column measurements are three dimensional (four including temporal dynamics) and data sets can quickly become large and complex
  - Determining whether inferences based on intensive study of limited areas can be extrapolated to other areas of the huge volume of the pelagic ocean
  - Achieving a balance between standard general observations and studies of particular phenomena.
- Addressing challenges:
  - Collaboration and data sharing among agencies
  - Establishing standard criteria for water column characterization data collection and monitoring
  - eDNA may be a way to address the time-consuming requirements of broad-scale biological observations
  - Machine learning and other AI based pattern sensing algorithms hold promise once adequate data are available
  - Physical sampling (including sampling archiving) in addition to sensor-based data collection will continue to be necessary

References

Netburn, A.N. (Editor). 2018. From Surface to Seafloor: Exploration of the Water Column (Workshop Report), Honolulu, HI, 4-5 March 2017. NOAA Office of Ocean Exploration and Research. Silver Spring, MD. NOAA Technical Memorandum OAR OER; 003. 34 pp. DOI: https://doi.org/10.25923/rnjx-vn79