NOAA West Coast Deep-Sea Coral Initiative 2018-2021: Final Report

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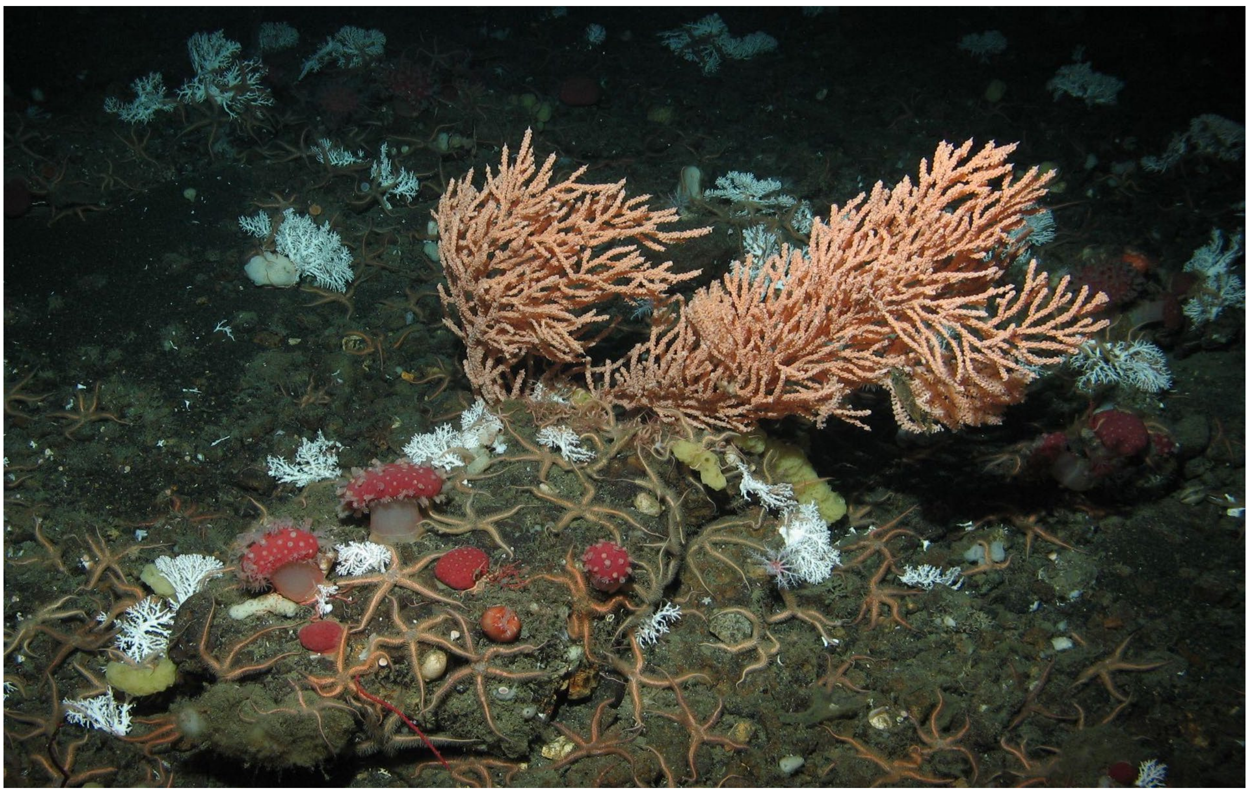

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[8]CSS, Inc. in support of NOAA National Centers for Coastal Ocean Science – Silver Spring, MD

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U.S. Department of Commerce
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National Oceanic and Atmospheric Administration
Richard Spinrad, PhD, NOAA Administrator

National Marine Fisheries Service
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About this report

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Cover image: A garden of red tree coral (center), red mushroom coral (front left), and white lace coral (various locations) with brittle stars at Mendocino Ridge (2018). This site had the highest density of corals observed during the entire initiative. Credit: NOAA/MARE.

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Abbreviations

AFSC	NOAA Alaska Fisheries Science Center
AUV	Autonomous Underwater Vehicle
BOEM	Bureau of Ocean Energy Management
BOSS	Benthic Observation Survey System
CBNMS	Cordell Bank National Marine Sanctuary
CHNMS	Chumash Heritage National Marine Sanctuary
CINMS	Channel Islands National Marine Sanctuary
CTD	Conductivity, Temperature, and Depth
DCEL	NOAA Deep Coral Ecology Laboratory
DECA	Deep-Sea Ecosystem Conservation Area
DFO	Department of Fisheries and Oceans (Canadian government)
DSCRTP	NOAA Deep Sea Coral Research and Technology Program
DSCS	Deep-sea corals and sponges
eDNA	Environmental DNA
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EFHCA	Essential Fish Habitat Conservation Area
EXPRESS	EXpanding Pacific Research and Exploration of Submerged Systems
GFMP	Groundfish Fishery Management Plan
GFNMS	Greater Farallones National Marine Sanctuary
GFOE	Global Foundation for Ocean Exploration
GIS	Geographic information systems
ID	Identification
MARE	Marine Applied Research and Exploration
MBA	Monterey Bay Aquarium
MBARI	Monterey Bay Aquarium Research Institute
MBNMS	Monterey Bay National Marine Sanctuary
MiTP	Mappers-in-Training Program
MPA	Marine Protected Area
NCCOS	NOAA National Centers for Coastal Ocean Science
NMS	National Marine Sanctuary
NOAA	National Oceanic and Atmospheric Administration
NOMEC	National Strategy for Ocean Mapping, Exploration, and Characterization
NWFSC	NOAA Northwest Fisheries Science Center
OCNMS	Olympic Coast National Marine Sanctuary
OCS	NOAA Office of Coast Survey
OET	Ocean Exploration Trust

ONMS	NOAA Office of National Marine Sanctuaries
PFMC	Pacific Fishery Management Council
RCA	Rockfish Conservation Area
ROV	Remotely Operated Vehicle
SCSMI	Southern California Seafloor Mapping Initiative
SESA	Sanctuary Ecologically Significant Area
SONAR	Sound Navigation and Ranging
SWFSC	NOAA Southwest Fisheries Science Center
WCDSCI	West Coast Deep-Sea Coral Initiative
WCGBTS	West Coast Bottom Trawl Survey
UCSB	University of California, Santa Barbara
USC	University of Southern California
USGS	United States Geological Survey

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Executive Summary

This report summarizes the objectives, accomplishments, and outcomes of the National Oceanic and Atmospheric Administration (NOAA) West Coast Deep-Sea Coral Initiative (WCDSCI), funded by the Deep Sea Coral Research and Technology Program[1] (DSCRTP). The four-year initiative (2018-2021) was designed to explore, map, characterize, and conduct research on deepwater coral and sponge habitats in the Pacific Fishery Management Council (PFMC) region, inclusive of waters off California, Oregon, and Washington. Rotating regional initiatives are a part of DSCRTP's national strategy to support deep-sea coral and sponge (DSCS) habitat research and management needs across the US. The first West Coast regional initiative took place in 2010-2012.

The West Coast marine region lies within the California Current Large Marine Ecosystem. Vibrant DSCS communities have been observed across a diversity of seafloor features throughout the region's Exclusive Economic Zone, including both soft and hard bottom substrates along features such as offshore seamounts, basins, oil and methane seeps, and submarine canyons. DSCS communities have been identified as Essential Fish Habitat (EFH) by PFMC as they provide a number of ecosystem services that are critical to the health of surrounding ecological communities as well as the economic systems they support, such as recreational and commercial fisheries. In spite of this, several natural and anthropogenic threats impact these habitats.

Bottom-contact fishing is a major threat to these long-lived, vulnerable systems. Some DSCS communities, however, are afforded protection through fishing restrictions established by the PFMC. For example, the Groundfish Fishery Management Plan established a number of Essential Fish Habitat Conservation Areas that restrict the use of bottom-contact fishing gears. In 2018, PFMC adopted Amendment 28 to the Groundfish Fishery Management Plan (implemented January 2020) which closed additional areas to bottom contact fishing gears, and re-opened some previously restricted areas to better balance sustainable fishing and deep-sea habitat conservation. In addition, National Marine Sanctuaries (NMS) also protect DSCS habitats from seafloor disturbances such as those related to seabed construction, cable laying, and oil or gas drilling/extraction.

The United States is driven to meet increasing energy needs and support the nation's blue economy through offshore wind infrastructure development. This and other blue economy initiatives with potential to impact the seafloor such as aquaculture, other types of renewable energy development, and deep-sea mining could threaten known and unknown DSCS ecosystems. Beyond physical disturbance from fishing gear and development, changes to environmental conditions as a result of climate change will likely have ubiquitous impacts on deep-sea communities across the globe.

One of the largest challenges facing resource managers' efforts to balance sustainable ocean use and deep-sea habitat conservation is the lack of high resolution seafloor mapping information

[1] NOAA Fisheries. 2023. Deep Sea Coral Research and Technology Program. [Available at https://deepseacoraldata.noaa.gov/]

and visual survey data across the US Exclusive Economic Zone. To prioritize filling these gaps the initiative began by forming a NOAA-led steering committee in 2018 with representatives from NOAA Fisheries Science Centers, Office of Habitat Conservation, Office of National Marine Sanctuaries, National Centers for Coastal Ocean Science, and the Pacific Fishery Management Council. The steering committee hosted a Priority Scoping Workshop in Santa Barbara, California where three major research themes were established and codified in the subsequent WCDSCI Science Plan. Overall, those that attended in-person and virtually agreed that the initiative should aim to (1) gather baseline information from areas subject to fishing regulation changes prior to, and following, the implementation of Amendment 28 to the Pacific Coast Groundfish Fishery Management Plan, (2) improve our understanding of known relatively high DSCS bycatch “hot spots,” and (3) explore and assess DSCS resources within NMS. Under consultation with the PFMC, the Science Plan outlined the potential partners, strategies and targeted field and data analysis projects to address the thematic foci identified in the workshop. Major components included large scale region-wide research cruises, as well as smaller scale targeted cruises, alongside mapping fieldwork, modeling, data rescue, data analysis, and genetics projects. An additional target in this initiative emphasized during the scoping workshop, included education and outreach product development.

Over the course of the initiative, three region-wide and several smaller scale research cruises were supported by WCDSCI. Two of the region-wide cruises advanced momentum initiated by the EXpanding Pacific Research and Exploration of Submerged Systems (EXPRESS) campaign, a cross federal agency (NOAA, BOEM, USGS) collaborative. As a result of the campaign, ship time, expertise, and other resources were leveraged to conduct 65 remotely operated vehicle (ROV) and 35 autonomous underwater vehicles (AUV) surveys across 29 unique sites and collect hundreds of biological, geological, and seawater samples. Sites were prioritized in areas subject to fishing regulation changes implemented by Amendment 28, sanctuaries, areas with known high bycatch of DSCS, and offshore wind energy planning areas. Significant findings included the identification of coral and sponge gardens at Mendocino Ridge, observations that extended the known ranges of multiple deepwater corals (*Primnoa pacifica* and *Stylaster parageus*), and observations that preliminarily confirmed areas re-opened to bottom-contact fishing by the PFMC were generally depauperate of DSCS communities. Despite the unprecedented circumstances caused by the COVID-19 pandemic, one additional region-wide expedition occurred in 2020 on the Ocean Exploration Trust’s E/V *Nautilus* in partnership with NOAA’s Office of Ocean Exploration and ONMS. Three expedition legs targeted visual surveys, collections, and telepresence-enabled outreach in one proposed and three existing West Coast sanctuaries. E/V *Nautilus’* telepresence system allowed sanctuary scientists and EXPRESS partners to remotely guide 24/7 ROV operations, which resulted in significant discoveries including several new habitats with high densities of DSCS, further evidence of a petrale sole spawning area in a proposed sanctuary, and an unknown glass sponge reef within Channel Islands NMS.

Smaller-scale research cruises targeted sanctuary priorities within the Olympic Coast, Monterey, Greater Farallones, and Channel Islands NMS. Ranging from 6-11 days at sea, ROVs or a drop camera were deployed to conduct visual surveys of the seafloor to identify DSCS species, map their distributions, and inform sanctuary management decisions related to these vulnerable habitats. This data will contribute to sanctuary managers' understanding of the distribution of resources within their boundaries, be incorporated into congressionally mandated condition reports, and support management plan updates and action plans.

The initiative also supported 12 associated studies. Referred to as small projects, these studies produced a variety of products and tools including: an online spatial prioritization tool to guide mapping, ROV/AUV site selection; the development of an image-based analysis of coral gardens; the acquisition and synthesis of seafloor mapping data across the West Coast; best practices for advanced habitat and distribution modeling of DSCS; a widely used targeted species collection list; a West Coast-wide identification guide for DSCS and fishes; advances in species identification, connectivity and environmental DNA (eDNA) studies; a comparative analysis of DSCS associations with groundfishes; annotated historical data sets; 3-dimensional photomosaics of DSCS habitats; an online geospatial learning portal for high school classrooms; and 3-dimensional printed models of DSCS specimens for sanctuary outreach kits. These studies are either completed or nearing completion despite encountering challenges related to the COVID-19 pandemic involving the delay or cancellation of ship time, restricted access to laboratories, office spaces and samples.

WCDSCI showcased an unprecedented level of collaboration among federal agencies to which much of the success of the initiative is owed, particularly with respect to executing region-wide field missions and leveraging additional funding. Through EXPRESS, cross-agency partnerships were built upon a solid foundation of communication where data needs, priorities, and resources were regularly shared. This foundation was critical for efficiently mobilizing the relevant technology, expertise, and other resources to address the broad array of science and management objectives determined at the priority scoping workshop. Inspired by the level of success in 2021, an EXPRESS-like campaign launched in Alaska known as Seascape Alaska. Overall, data collected and analyzed with WCDSCI support will inform a number of high priority, multi-agency management issues related to seafloor protections such as Essential Fish Habitat Conservation Areas, the development of offshore energy, the designation process and management of a new National Marine Sanctuary, and improved management of existing National Marine Sanctuaries. This initiative also focused resources on reaching a wide array of audiences in effort to connect people to these habitats that are remote and obscure, but important to the overall health of the ocean. From interactive, 3-dimensional digital models of DSCS species, to live streaming real time ROV footage, to serving freely available high school curricula, the initiative provided accessible and effective outreach that can build public awareness, interest, and support for DSCS ecosystems.

Section 1: Introduction

1.1 Overview of the US West Coast

The West Coast Deep-Sea Coral Initiative (WCDSCI) conducted research off the three contiguous West Coast states (Washington, Oregon, California) from ~50 m depth to the continental margin (Figure 1). The continental margin is characterized by a relatively narrow shelf and a steep continental slope, with the shelf break at approximately 200 m. This marine region is within the California Current Large Marine Ecosystem and includes two biogeographic provinces: the northern, cold-temperate Oregonian province and the southern, warm-temperate Californian province. The two provinces converge near Point Conception in southern California, marking a biogeographic break where many species reach their range limits. Frequent upwelling is also characteristic of both West Coast provinces where the strength, duration, and timing of events are highly influenced by El Niño Southern Oscillations, Pacific Decadal Oscillations, as well as the local bathymetry (Fautin et al., 2010). The resulting variability in surface primary productivity creates a dynamic and complex marine environment from surface to deep water habitats. Thriving shallow water and pelagic ecosystems supply deep-sea communities with sinking organic debris, a critical food source for deep-sea corals, sponges, and their associates (Druffel et al., 2016).

1.2 Deep-sea Corals and Sponges in the Region

Deep-sea corals and sponges (DSCS) have been observed throughout the US Exclusive Economic Zone (EEZ) off the West Coast by a variety of methods such as tow and drop cameras, manned and unmanned submersibles, and environmental DNA (eDNA), as well as samples from fishery bycatch and museum collections. DSCS are generally found in waters deeper than 50 m to more than 4,000 m deep (Everett et al., 2022), and can inhabit both soft and hard bottom substrates along various bathymetric features such as offshore seamounts, basins, oil and methane seeps, and submarine canyons. Communities of DSCS create complex and heterogeneous habitats on the seafloor, particularly when in dense aggregations, which support biodiversity hotspots in otherwise barren deep-sea environments (Buhl-Mortensen et al., 2010). DSCS ecosystems can provide important habitat for commercially and recreationally harvested species (Hourigan et al., 2017), and have been defined and protected as Essential Fish Habitat (EFH) by the National Oceanic and Atmospheric Administration (NOAA) in the West Coast Region. DSCS communities also provide a number of other vital ecosystem services such as sequestering and storing carbon and producing potential biomedical compounds, as well as other services yet to be understood by science (Armstrong et al., 2012).

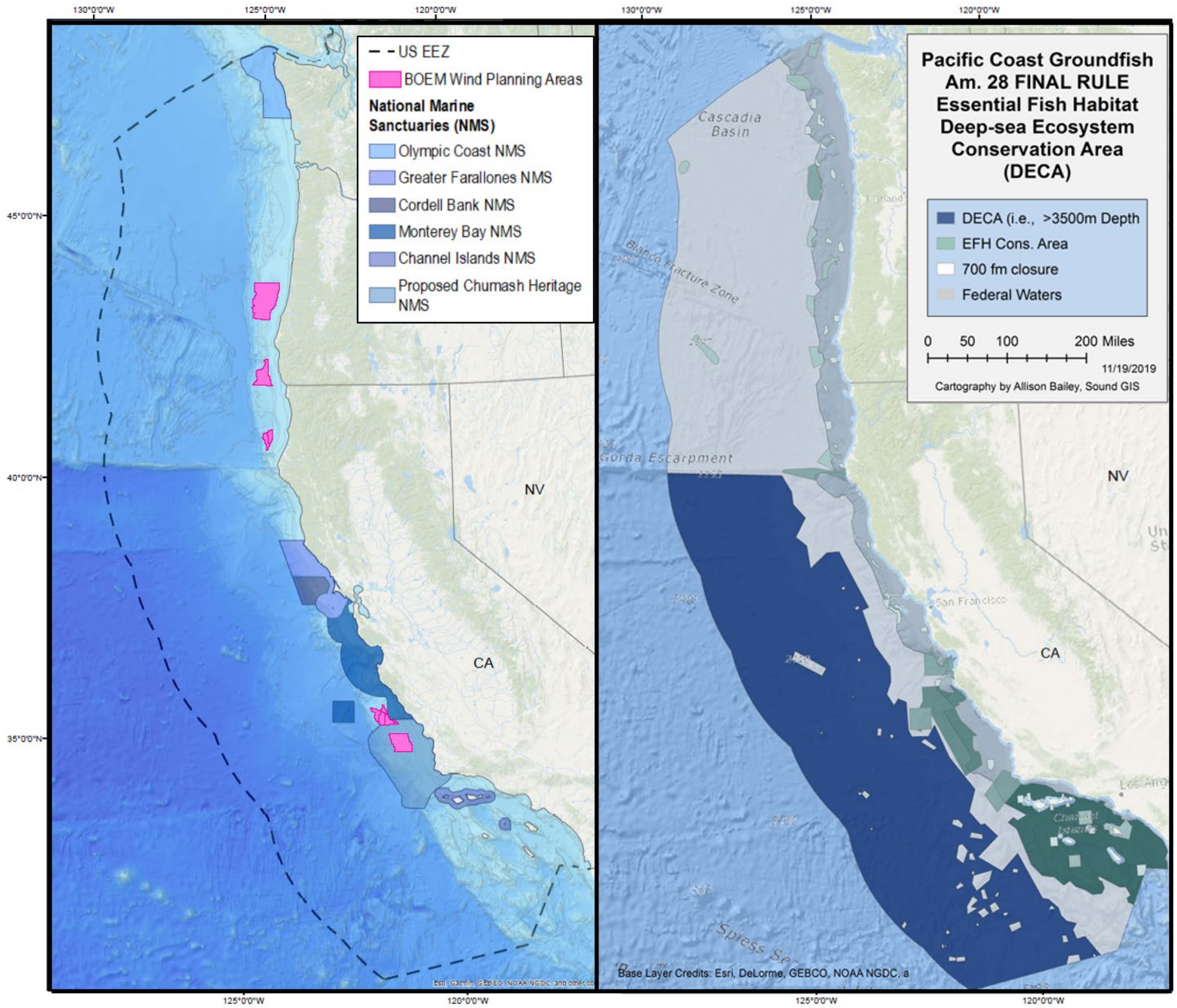

Figure 1. Maps of the US West Coast showing various types of protected areas such as National Marine Sanctuaries (blue shaded areas, left), wind planning areas as identified by Bureau of Ocean Energy Management (pink areas, left), Essential Fish Habitat (EFH) Conservation Areas (green areas, right) and the 700 fathom closure (gray, right), and the Deep-Sea Ecosystem Conservation Area (DECA, blue area, right).

1.2.1 Threats

The long-term persistence of DSCS ecosystems is at risk from a number of human activities. DSCS communities are particularly vulnerable marine ecosystems, as both DSCS are long-lived, slow growing, and take many years to reach reproductive maturity. Once damaged, DSCS may take decades or longer to recover, if they recover at all. Human activities that threaten DSCS along the West Coast may have direct or indirect impacts to these deep-sea habitats. Direct threats include physical disturbances to the seafloor while indirect impacts include alterations to deep-sea environmental conditions.

The most critical direct threat to DSCS ecosystems in the US is physical damage from bottom-contact fishing gear. On the West Coast, though the nature of the associations between demersal fishes and DSCS assemblages is less well defined (Bosley et al., 2020) than in other regions, the bottom trawls predominantly used by the groundfish fishery are responsible for the largest proportion of seafloor habitat disturbances and DSCS bycatch (Clarke et al., 2017; Benaka et al., 2019). Other gear types such as pots, traps, and longlines that likely result in habitat damage have been relatively less well studied (Rooper et al., 2017), but have a smaller overall footprint to bottom trawling. Offshore development threatens to damage benthic communities in deep waters as well.

In 2021, the Biden-Harris Administration called for the enhanced development of offshore wind energy in support of the nation's blue economy. As a result, the Bureau of Ocean Energy Management (BOEM) is moving forward with the leasing process of offshore wind energy areas in California, while Trident Winds has also submitted an unsolicited lease proposal for a floating wind project offshore of Grays Harbor, Washington. Seabed construction associated with offshore energy facilities will likely alter local environmental conditions for surrounding DSCS from increased turbidity and sediment plumes during construction, to longer lasting consequences from the structure's presence through sediment redistribution, altered surface currents and surface-derived carbon inputs (Poti et al., 2020). Advancing other blue economy initiatives such as aquaculture, other types of renewable energy, and potentially deep-sea mining could similarly alter local conditions to the detriment of DSCS ecosystems. Climate change related alterations to the ocean environment, such as increasing ocean acidification, hypoxia, increasing temperature, and anomalous weather events also threaten the survival of DSCS ecosystems globally.

In recent years, typical upwelling patterns and other oceanographic processes have been altered alongside the occurrence of extreme weather events such as marine heatwaves and extended hypoxic events (Harvey et al., 2017). Observed temperature anomalies that have severely impacted marine ecosystems were not only present at the sea surface, but also recorded at depths reaching at least 250 m (Grantham et al., 2004; Gugliotti et al., 2019). Presently, the consequences of such anomalies are better understood for marine life in the upper portion of the water column than for deep water marine life. Such climate change related issues will likely continue to disrupt ocean conditions, particularly in the northern extent of this geography. For a more thorough discussion of potential threats to DSCS on the West Coast, see Clarke et al. (2017).

1.2.2 Deep-Sea Coral and Sponge Resource Management

In light of these threats, the Pacific Fishery Management Council (PFMC) and NOAA have been protecting DSCS, both directly and indirectly, mainly through groundfish fishery management measures. DSCS ecosystems are among the habitat types that benefit from the network of Essential Fish Habitat Conservation Areas (EFHCAs)[2] that prohibit bottom trawling and, in some cases, other types of fishing gears that contact the seafloor. DSCS and surrounding benthic

[2] NOAA Fisheries. 2023. West Coast Groundfish Closed Areas. [Available at https://www.fisheries.noaa.gov/west-coast/sustainable-fisheries/west-coast-groundfish-closed-areas]

habitats are also indirectly protected by bottom-trawl closures designed to minimize bycatch of overfished species, such as Rockfish Conservation Areas (RCAs) and Cowcod Conservation Areas. How much DSCS habitat resides within the bottom-trawl closed areas is not clear based on the general lack of high resolution mapping and visual survey data throughout the region.

In April 2018, the PFMC approved Amendment 28 to the Groundfish Fishery Management Plan[3] (GFMP), which was implemented by NOAA Fisheries in January 2020 (Figure 2). Amendment 28 modified the suite of EFHCAs and eliminated (i.e., reopened to bottom-contact fishing) the trawl RCA off Oregon and California, but did not change management within federal waters off Washington State due to the presence of Coastal Treaty Tribes and the need for additional tribal consultation. In addition, Amendment 28 established the Deep-Sea Ecosystem Conservation Area (DECA), which closed areas within the EEZ deeper than 3,500 m to bottom contact gear. Because the DECA exceeds the deepest extent of Pacific Coast Groundfish EFH, it was established under the discretionary provisions in section 303(b)(2)(B) of the Magnuson-Stevens Fishery Conservation and Management Act. This PFMC action was informed by data in the NOAA Deep-Sea Coral Data Portal and National Database[4] (Hourigan et al., 2015), as well as input from the fishing industry. The reopened areas, closed to bottom trawling for 12-16 years, present a rare opportunity to study the recovery potential of DSCS. Although comprehensive substrate data are unavailable for this large area of the US EEZ, numerous observations of DSCS have been recorded throughout the areas subject to regulation changes.

[3] Pacific Fishery Management Council. 2020. Groundfish FMP Amendment 28: Essential fish habitat. [Available at https://www.pcouncil.org/actions/amendment-28-pacific-coast-groundfish-essential-fish-habitat-rockfish-conservation-area-modifications-and-magnuson-act-discretionary-closures/]

[4] NOAA National Centers for Environmental Information. 2023. NOAA Deep-Sea Coral & Sponge Map Portal. [Available at https://www.ncei.noaa.gov/maps/deep-sea-corals/mapSites.htm]

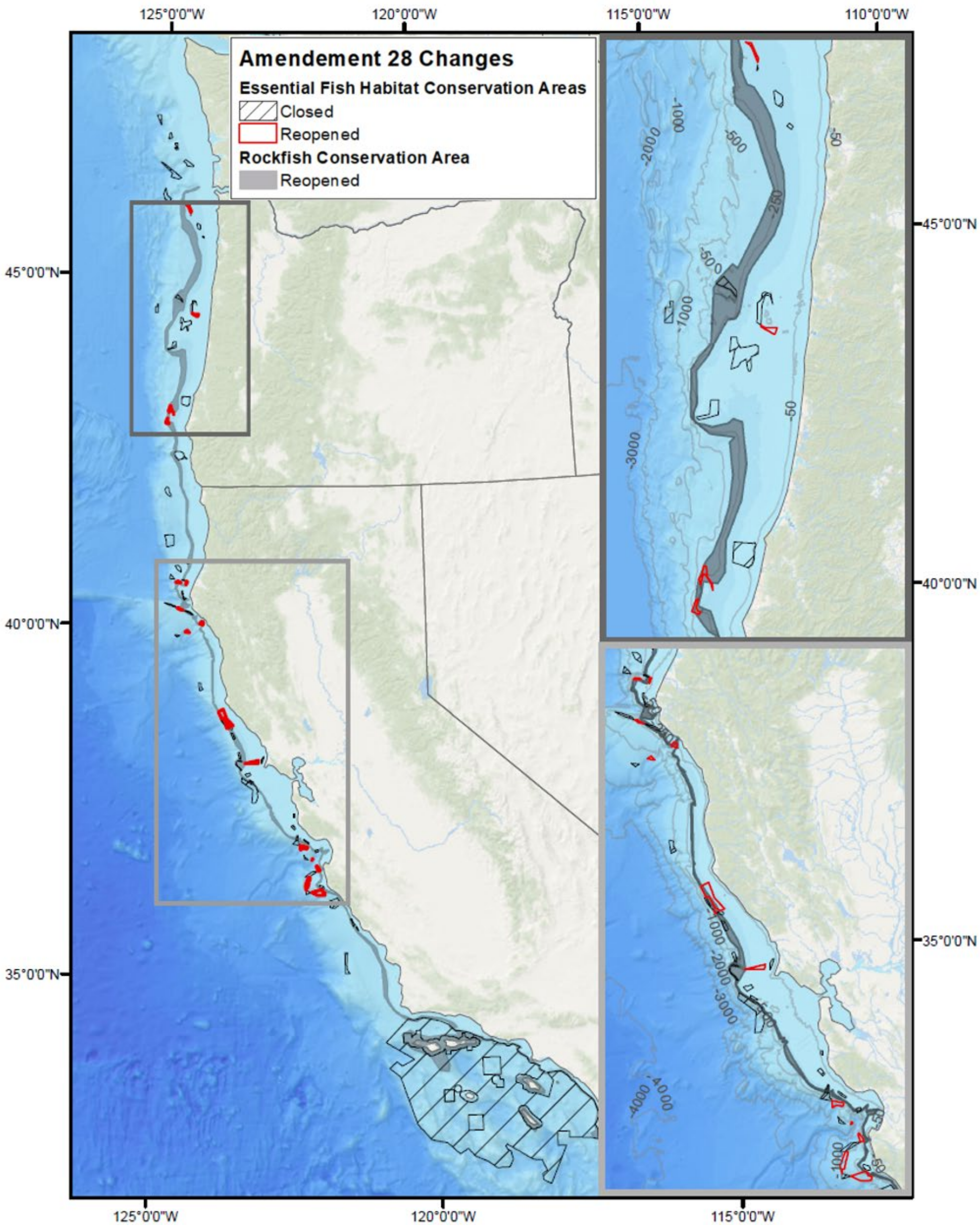

Figure 2. A map of the Essential Fish Habitat Conservation Area and Rockfish Conservation Area regulation changes implemented by Amendment 28 to the Groundfish Fishery Management Plan.

NOAA has also provided protections to DSCS through establishment, management, and expansion of five National Marine Sanctuaries (NMS) on the West Coast. Channel Islands NMS (CINMS), Monterey Bay NMS (MBNMS), Greater Farallones NMS (GFNMS), Cordell Bank NMS (CBNMS), and Olympic Coast NMS (OCNMS) afford protections to seafloor habitat and known DSCS communities. A sixth sanctuary, the Chumash Heritage NMS (CHNMS) has been nominated and is currently undergoing public scoping as dictated by the NMS designation[5]

[5] NOAA National Marine Sanctuaries. 2023. Designations. [Available at https://sanctuaries.noaa.gov/management/designations.html]

process. The boundaries and protection measures of this new sanctuary between CINMS and MBNMS will be determined through an environmental impact analysis that considers a range of alternatives, proposed regulations, and proposed boundaries. Each West Coast sanctuary is guided by specific management plans tailored to address site-specific issues, and each brings unique perspectives to seafloor and DSCS protection efforts. Collectively, NMS generally provide protection to DSCS habitats through the prohibition of or permitting of activities that have the potential to alter the seafloor and disturb vulnerable benthic resources. Examples include oil and gas exploration and extraction, deep-sea mining, and cable laying. Activities that contribute to research, monitoring, and management of sanctuary resources must also be reviewed and permitted by individual sites to minimize the risk of seafloor disturbance. While the sanctuaries do not regulate fishing activities, staff at these sites are actively involved in understanding potential impacts to sanctuary resources and regularly collaborate with indigenous communities, commercial and recreational anglers, conservationists, resource managers, and other interested parties through the PFMC. Despite understanding the importance of thriving DSCS communities in these special places, only a small portion of the deep-sea habitats within sanctuaries have been explored and even fewer have been characterized.

Given the (1) sensitivity and vulnerability of DSCS ecosystems, (2) numerous threats they face now and additional threats anticipated in the future, (3) recognition by management agencies that these ecosystems are valuable and in need of protection, and (4) general lack of information regarding DSCS presence and distribution, scientists and managers are in critical need of baseline data to inform management efforts that aim to conserve DSCS ecosystems.

1.3 The West Coast Deep-Sea Coral Initiative

NOAA established the Deep Sea Coral Research and Technology Program (DSCRTP) under the authority of the Magnuson-Stevens Fishery Conservation and Management Act, as reauthorized in 2007. The goal of DSCRTP is to provide scientific information needed to manage, conserve, and protect DSCS ecosystems throughout the US, as these ecosystems create important biogenic habitats and support remarkably complex communities in deep waters around the globe (NOAA 2010, Hourigan 2017). To carry out this mission, DSCRTP supports rotating multi-year fieldwork initiatives across each region that produce new research along with analyses of new and historical data. Since its inception, DSCRTP has conducted two research initiatives (2010-2012 and 2018-2021) in the West Coast region. fieldwork has included mapping, quantitative visual surveys and sample collection conducted in consultation with the PFMC, and in collaboration with NOAA Fisheries Science Centers, National Centers for Coastal Ocean Research (NCCOS), Office of National Marine Sanctuaries (ONMS), Office of Ocean Exploration, as well as other federal agencies, academic partners, industries, and non-government organizations that collect and analyze information on DSCS location, biology, ecology, and potential anthropogenic impacts.

This report presents the results to-date of the second regionally-led research program on the West Coast, referred to as the West Coast Deep-Sea Coral Initiative (WCDSCI or “initiative”). Highlights from the 2018-2021 initiative are summarized below. The report concludes with a list of future administrative and scientific priorities and recommendations as recorded by WCDSCI participants, partners, and collaborators.

1.4 Initiative by the Numbers

- 36,199 km^2 of high resolution seafloor mapping data processed
- 137 remotely operated vehicle (ROV) dives, 42 autonomous underwater vehicle (AUV) dives, and 113 Benthic Observation Survey System (BOSS) lander drops
- 62 sites characterized biologically (29 sites in three published reports, 33 sites from reports yet to be completed)
- 12 sites surveyed within wind energy planning areas
- 17 sites surveyed within EFHCAs that underwent protection modifications under Amendment 28 to the Groundfish Fishery Management Plan
- 102 visual surveys conducted within National Marine Sanctuaries
- 25 visual surveys conducted within the proposed Chumash Heritage National Marine Sanctuary
- Collections of potentially new DSCS species (on-going): 19 demosponges, 3 glass sponges, and 2-3 corals
- 369 DSCS samples collected to further biological studies
- 163 eDNA samples collected in DSCS habitats
- 9 noted range extensions for corals (4) and sponges (3)
- 16 historical video data sets reviewed for coral, sponge, and fish assemblages
- >15 student interns, fellows, scholars that were provided training and career development opportunities
- > 50 collaborators across federal, state and tribal government organizations, NGOs, and academia

1.5 Significant Research Accomplishments and Findings

Cruises

- Executed two keystone field cruises each 30 days in length as part of Expanding Pacific Research and Exploration of Submerged Systems campaign, surveying from southern Washington south to southern California
- Executed first remote field operation with Ocean Exploration Trust led by PIs ashore due to COVID-19 pandemic
- Discovered and characterized a petrale sole spawning aggregation site over Santa Lucia Bank
- Discovered a novel glass sponge reef in the Channel Islands National Marine Sanctuary; while the bulk of the reef is no longer living there are still many live remnants
- First quantitative surveys of Sverdrup Bank
- First use of telepresence on a NOAA Fisheries Vessel to explore DSCS on the West Coast
- Revisitation of Coquille, Daisy and Santa Lucia Bank first surveyed in 2005 to monitor impacts of management measures implemented in early 2000s

Product Highlights

- Spatial prioritization tool and digital data atlas for the West Coast
- Updated and unified seafloor bathymetry surfaces for the West Coast
- Draft west-coast wide species identification guide for corals and sponges
- Photomosaics of undersea habitats to support engagement and outreach efforts
- 3D models of DSCS specimens developed for incorporation into K-12 education
- Educational curricula on managing the deep sea developed in collaboration with SeaSketch
- Best practices for modeling DSCS species distributions

Other

- Accomplished unprecedented level of collaboration across NOAA, United States Geological Survey (USGS), BOEM, and Monterey Bay Aquarium Research Institute (MBARI) through established EXpanding Pacific Research and Exploration of Submerged Systems (EXPRESS) campaign
- Advanced eDNA technology and the expansion of sequencing databases as applied to DSCS
- Supported the 'Into the Deep' exhibit at the Monterey Bay Aquarium (MBA)
- Furthering the development of artificial intelligence efforts to characterize the deep sea

Section 2: Major Field Research Projects

2.1 General Fieldwork Objectives and Approach

The Science Plan[6] that guided this initiative was developed in collaboration with over 40 experts from NOAA, PFMC, BOEM, USGS, Fisheries and Oceans Canada (DFO), Ocean Exploration Trust (OET), Quileute Tribe, Makah Tribe, Northwest Indian Fisheries Commission, academic institutions, and other NGOs and stakeholders. During the 2018 Science Priority Scoping Workshop,[7] the science and management community emphasized the importance and value of prioritizing and strategically executing field missions to collect new information on the presence, abundance, and condition of DSCS and associates in order to:

1) Gather baseline information from areas subject to fishing regulation changes prior to, and following, the implementation of Amendment 28 to the Pacific Coast GFMP.
2) Improve our understanding of known relatively high DSCS bycatch "hot spots."
3) Explore and assess DSCS resources within NOAA National Marine Sanctuaries with emphasis on areas of sanctuary resource protection and management concerns.

Ultimately, five field missions were primarily supported by the initiative as well as two others that were funded in part. All fieldwork summarized below met one or more of the above

[6] NOAA. 2019. West Coast Deep-Sea Coral Initiative Science Plan (2018-2021). [Available at https://deepseacoraldata.noaa.gov/publications]
[7] NOAA. 2018. Research Priorities Workshop Report for the DSCRTP West Coast Research Initiative. [Available at https://deepseacoraldata.noaa.gov/publications]

priorities and together spanned the entire West Coast from Washington's Olympic Coast to southern California's Channel Islands (Figure 3). Survey locations were determined based on their relevance to the core initiative goals and the availability of operating platforms, personnel, and technology.

The technology deployed varied among cruises, but similar methodologies were used whenever possible to ensure some level of comparison is possible among sites. Quantitative transects were prioritized during visual surveys, and to the extent practical, ROV and AUV technology maintained a consistent height above the seafloor, heading and speed over ground. Thus, for site characterizations and other future publications, the relative abundance, densities, and other quantitative metrics commonly determined for DSCS, associates, fishes, marine debris, or substrate type can be calculated. Video and image data were annotated by a group of experts from NOAA ONMS, Fisheries, and NCCOS, and observation records were submitted to DSCRTP's National Database[8].

Where possible, water, biological and geological samples were collected. Samples were processed for eDNA, stable isotopes, particulate organic matter, or taxonomic identification. For genetic studies, similar methods for collecting, processing, and archiving were used across field missions. Samples collected for genetic studies included DSCS collected for inclusion in the DNA voucher collection, for genetic clarification of taxonomy, and samples to be included in population connectivity studies. Primary samples were all preserved in 95% ethanol and are currently archived at Northwest Fisheries Science Center (NWFSC) for analysis. Detailed molecular methods are included in relevant sections below. Water for eDNA analysis was filtered aboard the vessel and preserved in Longmire's lysis buffer (Longmire et al. 1997) for transport back to NWFSC. All eDNA samples are archived at NWFSC for ongoing analysis (described below).

[8] NOAA National Centers for Environmental Information. 2023. NOAA Deep-Sea Coral & Sponge Map Portal. [Available at https://www.ncei.noaa.gov/maps/deep-sea-corals/mapSites.htm]

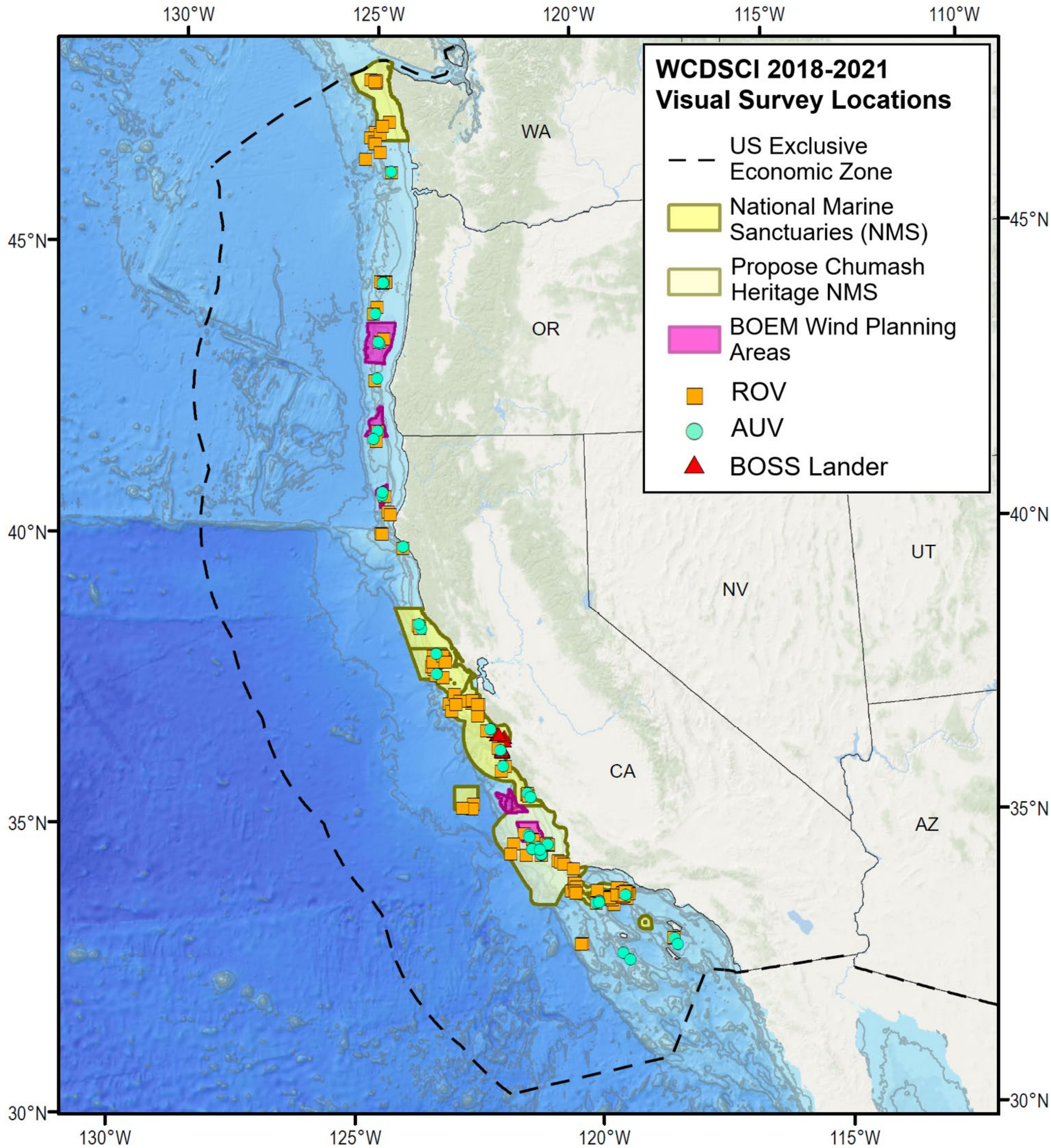

Figure 3. A map of the dive locations of all WCDSCI-supported visual surveys. Surveys were conducted using remotely operated vehicles (ROV), autonomous underwater vehicles (AUV), or a Benthic Observation Survey System (BOSS) video lander.

Table 1. Research expeditions supported by WCDSCI from 2018-2021.

Survey ID	Lead(s)	Ship	Vehicle(s)	Region	Mapped (km^2)	ROV Dives	AUV Dives	Lander Drops	Start date	End date
SH1809	Dani Lipski, Jan Roletto	*Bell M. Shimada*	*Beagle*	GFNMS, CBNMS, northern MBNMS	300	15	0	0	7/30/18	8/10/18
SH1812	Elizabeth Clarke, Tom Laidig	*Bell M. Shimada*	*Beagle, Popoki*	West Coast (OR-CA)	0	37	24	0	10/9/18	11/8/18
n/a	Peter Etnoyer, Chris Caldow	*Shearwater*	*Beagle*	CINMS	0	17	0	0	6/4/19	6/13/19
SH1907	Jenny Waddell	*Bell M. Shimada*	*Beagle*	OCNMS	0	5	0	0	9/10/19	9/16/19
RL1905	Elizabeth Clarke, Tom Laidig	*Reuben Lasker*	*Yogi, Popoki*	West Coast (WA-CA)	0	19	19	0	10/4/19	11/7/19
NA121	Jenny Waddell	*Nautilus*	*Hercules*	OCNMS	1,506	5	0	0	9/20/20	10/1/20
NA122	Chad King, Jan Roletto	*Nautilus*	*Hercules*	MBNMS	10,300	5	0	0	10/5/20	10/15/20
NA123	Lisa Wooninck, Lizzie Duncan	*Nautilus*	*Hercules*	CINMS	0	10	0	0	10/16/20	10/26/20
n/a	Erica Burton, Rick Starr, James Lindholm	*Fulmar*	Video lander	MBNMS	0	0	0	113	10/7/20	10/17/20
n/a	Dani Lipski, Jan Roletto	*Fulmar*	*Beagle*	GFNMS, CBNMS, northern MBNMS	0	9	0	0	8/18/21	8/30/21

2.2 EXpanding Pacific Research and Exploration of Submerged Systems (EXPRESS) Keystone Cruises

2.2.1 Background and Objectives

Two 30-day cruises occurred in the fall of 2018 and 2019 aboard NOAA Ships *Bell M. Shimada* (SH-18-12) and *Reuben Lasker* (RL-19-05), respectively. The cruises surveyed predetermined sites along the coast from Daisy Bank (central Oregon, 2018) and Willapa Canyon (southern Washington, 2019) in the north to southern California. Based on recommendations that came out of the WCDSCI Science Priorities and Scoping Workshop, sites were chosen because they met one or more of the following criteria: 1) EFH areas scheduled to have the protections modified by Amendment 28, 2) within sanctuary boundaries, 3) new areas with no DSCS data, or 4) were sites that had been surveyed years ago and provided opportunities to resurvey and evaluate assemblage changes. Although these cruises aimed to span the entire West Coast, time and port locations logistically constrained the reach into the northernmost part of Washington State and therefore excluded work in OCNMS.

These two cruises represented a major contribution of WCDSCI to the EXPRESS campaign, and mobilized collaboration from multiple EXPRESS partners. This campaign combines researchers from federal agencies and nonfederal institutions in collaborative science targeting deepwater areas off California, Oregon, and Washington. EXPRESS researchers leverage funding, resources, personnel, and expertise to accomplish more science than would have occurred by a single entity alone. For these coastwide surveys, WCDSCI researchers partnered with EXPRESS researchers from NOAA (Northwest and Southwest Fishery Science Centers (SWFSC); Channel Islands, Cordell Bank, Greater Farallones, and Monterey Bay NMS); and BOEM, USGS, and MBARI. Thus, data collected during these missions not only address WCDSCI priorities, but also those of EXPRESS.

There were eight specific objectives for these research cruises:

1) Collect EFHCA baseline information at 17 sites proposed for modification by the PFMC.
2) Revisit previously surveyed sites to document if changes have occurred over time.
3) Collect information to validate BOEM-supported deep-sea coral cross-shelf habitat suitability models.
4) Collect samples to help in identifying West Coast DSCS and apply NOAA prioritized emerging technologies including 'Omics tools, Uncrewed Systems, and Artificial Intelligence to enhance these surveys and collections.
5) Collect data in emerging areas of interest for wind energy development.
6) Collect water samples for coastwide eDNA and water chemistry studies.
7) Collect data on coral, sponge, and fish assemblages in National Marine Sanctuaries.
8) Create 3D photomosaics of benthic habitats to assist characterization and support sanctuary outreach.

2.2.2 Approach

At each site, ROV and AUV surveys were completed to assess the DSCS and fish assemblages. ROVs collected invertebrate and geologic samples along with at least one water sample, if possible. In 2018, the Marine Applied Research and Exploration (MARE) ROV, *Beagle* (600 m max depth), was used for surveys and in 2019, the Global Foundation for Ocean Exploration (GFOE) ROVs, *Yogi* and *Guru* (1500 m max depth), were used. NOAA Fisheries' AUV, *Popoki* (2000 m max depth), was deployed both years. ROV surveys were conducted in waters 50-600 m deep in 2018 and 190-1245 m deep in 2019. Each ROV dive was split between sample collection, species investigations and quantitative visual transects. ROV transects covered 200-300 m of sea floor and lasted for approximately 15-25 min depending on terrain. AUV transects were conducted during most dives, lasting 5-7 hours each, where still images were captured approximately every eight seconds. In addition to quantitative visual transect surveys, on occasion the AUV collected densely overlapping images for constructing photomosaics. AUV and ROV dive surveys were non-overlapping to cover more area and help to better characterize the seafloor assemblages in each site.

A shipboard Conductivity, Temperature, and Depth (CTD) cast was attempted at each ROV dive site and water samples were collected at discrete depths for water chemistry and eDNA analyses. The ROVs and AUV had onboard CTDs and each ROV was equipped with one or two Niskin bottles to collect water samples during the dive. The AUV also collected oxygen information every 30 seconds. A miniature autonomous plume recorder was also mounted on the AUV and recorded light-backscattering (for suspended particle concentrations) and oxidation-reduction potential (for detecting the presence of reduced chemical species). The ROVs collected biologic samples at each dive site and these were identified (or given a tentative identification), labeled, and either preserved in alcohol or frozen, and initially archived at NWFSC. Eventually, select specimens will be permanently archived at either the Smithsonian Institution's National Museum of Natural History or the California Academy of Science.

ROV video and AUV still images were reviewed for the presence of DSCS and fishes. Invertebrate and fish data were pooled per site to get a density of each taxa at each site. All individuals were identified to the lowest taxa, enumerated, and their length was measured (total length for fishes and longest height and width for DSCS. Select DSCS samples were sent to experts for identification and all water sample filters were sent to interested researchers. Samples collected during the EXPRESS cruises were included in ongoing DNA barcoding, eDNA sequencing, population connectivity and taxonomy studies. The data from these cruises are currently being analyzed and will be available in site characterization reports or peer-reviewed papers in the future.

2.2.3 Significant Results to Date

For the EXPRESS 2018 cruise, 15 dives were completed using the AUV and 37 by the ROV (totaling 150 quantitative ROV transects) across 15 sites from central Oregon to Sverdrup Bank in southern California. A total of 123 water chemistry samples were collected along with 27 eDNA, 41 coral, 54 sponge, and 10 geologic samples.

For the EXPRESS 2019 cruise, the AUV completed 20 dives and the ROV completed 18 dives and 50 quantitative transects over 15 sites from Willapa Canyon in southern Washington to the Santa Catalina Basin in southern California. More than 700 water chemistry samples were collected along with 57 samples for eDNA analysis, 33 corals, 44 sponges, and 10 geologic samples.

Table 2. Dive sites (AUV and ROV) and the objectives accomplished at each site targeted by the 2018 and 2019 EXPRESS field missions.

	Objective							
	1	2	3	4	5	6	7	8
Dive Sites	EFHCA	Revisit	Validate	Collections	Wind	Water samples	NMS	Photo-mosaic
Willapa Canyon	□		□	□		□		
Daisy Bank	□	□	□	□		□		
Heceta Bank			□	□		□		
Sponge Bycatch			□	□		□		
Mud Volcano			□	□		□		
Bandon High Spot	□	□	□	□		□		
Brush Patch	□		□	□		□		
Humboldt Wind Energy			□	□	□	□		
Eel River Canyon	□		□	□		□		
Mendocino Ridge	□		□	□		□		
Delgada Canyon	□		□	□		□		
Pt. Arena	□		□	□		□	□	
Cordell Bank NMS			□	□		□	□	
Cabrillo Canyon	□		□	□		□	□	
West Carmel Canyon	□		□	□		□	□	
Sur Slot Canyons	□		□	□		□	□	
La Cruz Canyon	□		□	□		□	□	□
Santa Lucia Bank	□	□	□	□	□	□		
Pt. Conception			□	□		□		
South Santa Rosa Island	□	□	□				□	□
Gull Island (SCI)	□		□	□		□	□	
NE Santa Cruz Island			□	□		□	□	
Santa Cruz Island South	□		□	□		□	□	
Anacapa Island North			□	□		□	□	
Anacapa Island South			□	□		□	□	
Sverdrup Bank	□		□	□		□		
Santa Catalina Basin	□	□	□	□		□		

Coral and sponge densities at Mendocino Ridge were high enough to be considered coral and sponge “gardens.” This area had the highest density of corals (613 corals/100 m^2) and the second highest density of sponges (103 corals/100 m^2) observed during the entire initiative. Mushroom corals (*Heteropolypus ritteri*), red whip corals (*Swiftia* type (red skeleton with unknown polyp color); *Swiftia* spp.), and white hydrocorals (*Stylaster parageus*) were the most abundant corals with 28,730 individuals counted over two dives (Figure 4). Abundant sponge taxa were yellow upright flat sponges (*Mycale* spp.), Picasso sponges (*Staurocalyptus* spp.), and barrel sponges. The area surveyed ranged from 356-511 m deep and the entire survey area (4,741 m^2) was covered in corals and sponges. Two coral range extensions were noted in this area (*Primnoa pacifica* and *Stylaster parageus*), extending southward from Washington to northern California. More surveys are needed in this area to determine the extent of these gardens and to better understand the amazing habitat formed by these invertebrates.

Although Mendocino Ridge had an abundance of corals and sponges, fish densities were the lowest in all the 2018 surveyed sites. This site was one of the deeper dives (as noted by deep-living species like sablefish, thornyheads, and blackgill rockfishes) which may account for the decreased number of fishes observed. Still, there were some unusual northern species observed here. The only Aleutian skate and one of the two shortraker rockfish were observed here. Surprisingly, even with the high numbers of corals, only 2% of the fishes were associated with corals or sponges.

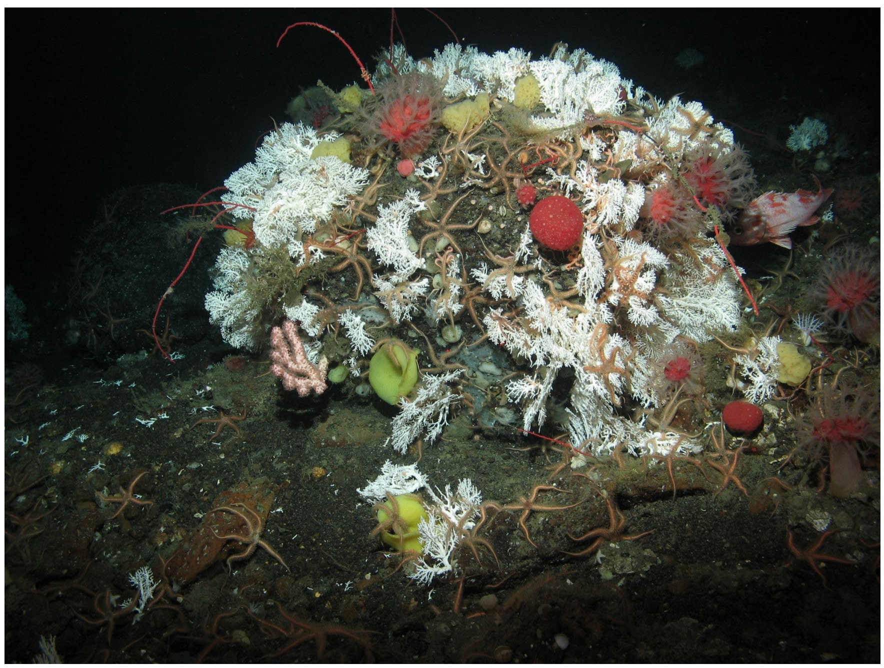

Figure 4. A boulder covered in white hydrocorals, red mushroom corals, red whip corals, pink *Paragorgia* spp., and many yellow and white sponges on Mendocino Ridge at 429 m depth.

The 2019 EXPRESS mission on the *Lasker* was the first instance of telepresence technology being used on a NOAA Ship, as well as GFOE's first opportunity to test its mostly self-contained "flyaway" telepresence system (Figure 5). The test was successful and provided a rare opportunity to connect live with the public as well as other scientists by livestreaming the ROV footage on GFOE's YouTube site, GFOE's and NOAA Ocean Exploration's home pages, and a slack channel for scientists ashore. In addition to livestreaming the ROV footage, several ship-to-shore interactions were held with the Exploratorium, facilitated by Marry Miller (Director of the Exploratorium's Environmental Science Partnerships Program) and an elementary school in Ventura, California, facilitated by Jeremy Potter and John Romero (BOEM). Each of these interactions allowed students and the public to have their questions answered in real time by scientists, engineers, and other professionals onboard the *Lasker*. In addition, the Exploratorium and EXPRESS partners co-hosted a special event (ship tour, discussion with scientists, and a lunch) while the *Lasker* was in port at the midpoint of the expedition. The event was held to highlight the success of the intra- and inter-agency partnerships of the EXPRESS campaign with federal and state agency leaders, as well as how field missions support and inform critical decision making processes related to our ocean's natural resources.

Figure 5. Left: The "flyaway" telepresence system owned and operated by GFOE on NOAA Ship *Reuben Lasker* during the 2019 EXPRESS cruise. Right: A photo of the shoreside point of view of the Exploratorium in San Francisco, California, with students and the public asking questions to several scientists onboard the *Lasker*. Photos courtesy of NOAA Ocean Exploration and the Exploratorium, respectively.

Highlights from both cruises include the following:

1) First successful use of a flyaway telepresence system on a NOAA Fisheries vessel.
2) First quantitative survey of Sverdrup Bank in southern California.
3) Discovered a large coral and sponge garden at Mendocino Ridge that contained two coral range extensions.
4) 29 unique sites surveyed and >120,000 m^2 of seafloor habitat surveyed.
5) video and still images were used to positively identify difficult to distinguish species (*Icelinus* sculpins, deepwater poachers, grenadiers) *in situ* for the first time.
6) Successfully brought together collaborators from NOAA, BOEM, USGS, and the University of California, Santa Barbara (UCSB).
7) Resurveyed a dying sponge reef in Catalina Basin after 35 years.

For more detailed information, please see site characterization reports for the 2018 and 2019 EXPRESS cruises (Laidig et al., 2021; 2022).

2.2.4 Next Steps

Analysts will combine DSCS, fish and other data to: produce coastwide distributional models, identify high density areas of DSCS, and examine the changes in association of fishes and DSCS (section 4.8) along the coast. These data will enhance understanding of the ecosystem functions of section DSCS and can be used to help managers improve management measures and select areas for protection. In addition, experts are continuing to identify DSCS samples and process them for genetic and genomic analyses. These data will be used to complete a coastwide DSCS guide (Section 4.6) and will also contribute to ongoing population connectivity and taxonomy studies for individual DSCS taxa collected during these cruises (section 4.7).

2.3 Research Cruise to Olympic Coast National Marine Sanctuary on NOAA Ship *Bell M. Shimada:* 2019 (SH-19-07)

2.3.1 Background and Objectives

From September 10-16, 2019, collaborators from MARE joined staff from across NOAA to conduct a deep-sea ecosystem research cruise off Washington State in OCNMS. The team used MARE's ROV *Beagle* in a topographically complex area of central Juan de Fuca Canyon, within and adjacent to the 'Olympic 2' EFHCA, which was designated for protection in 2006 by PFMC (Figure 6). This project directly targeted larger initiative priorities related to exploring sanctuaries and gathering information in protected areas such as EFHCAs.

2.3.2 Approach

The primary goal of the 7-day mission aboard NOAA Ship *Bell M. Shimada* was to visually survey priority seafloor locations within and adjacent to OCNMS. The team conducted five ROV dives, completing 19 standardized quantitative visual transects within various seafloor habitat types in and around the 'Olympic 2' EFHCA (Figure 7). In addition to this primary objective, the mission allowed OCNMS to achieve complementary research objectives, such as by using nighttime hours to conduct CTD casts and plankton surface trawls, and NOAA Pacific Marine Environmental Laboratory partners to recover and re-deploy an important acoustic mooring (Noise Reference Station 03).

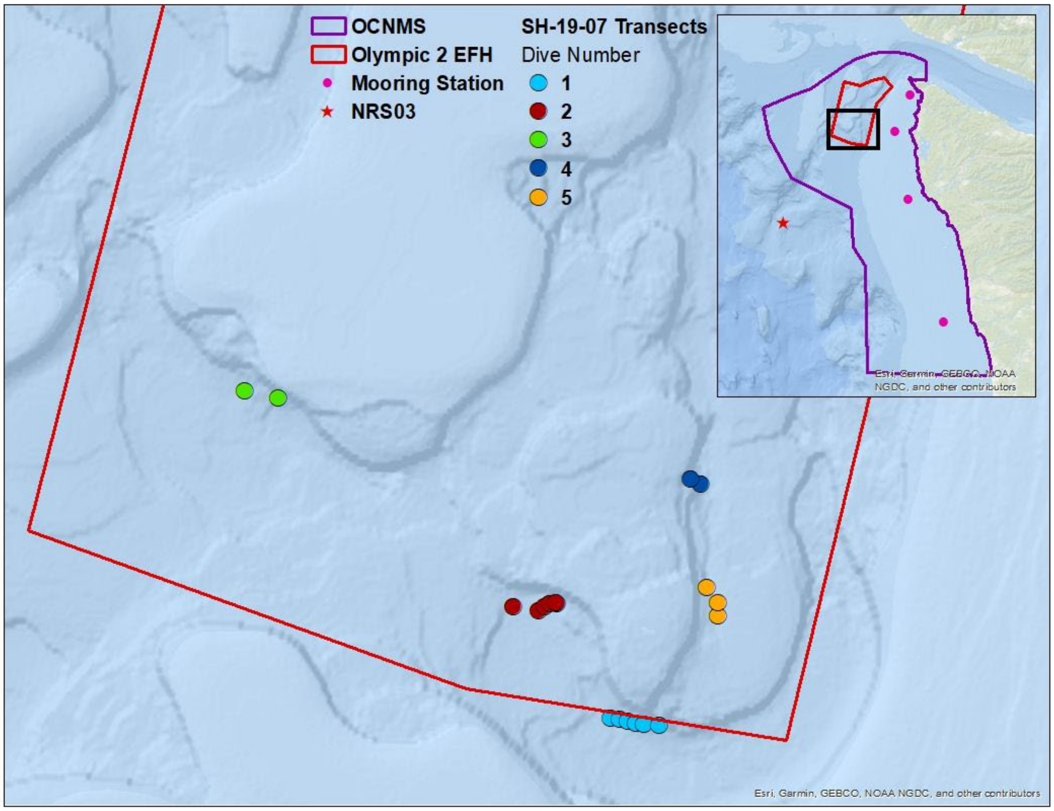

Figure 6. A map of locations targeted for quantitative visual transects with ROV *Beagle* during the September 2019 research cruise to Olympic Coast National Marine Sanctuary on NOAA Ship *Bell M. Shimada*. Five ROV dives were conducted, involving 19 transects, which are indicated by circles and color-coded by dive.

2.3.3 Significant Results to Date

Detailed results from the cruise are summarized in an online report that may be found at DSCRTP's data portal, linked above. Briefly, the ROV conducted visual surveys over two different major seafloor features of interest, both of which lie mostly inside Olympic 2 EFHCA. As sea conditions allowed, the team conducted five ROV dives off the *Shimada* to explore and sample areas of high complexity and interest for DSCS communities. Nineteen quantitative video transects of the seafloor were analyzed by WCDSCI experts for fish, coral, sponge, and other invertebrate identification. The timed transects captured more than 20 hours of video and thousands of still images of benthic habitat. While on transect, at least 15 different species of corals were preliminarily observed. In addition, numerous species of DSCS and other invertebrates such as octopus and crabs, and commercially harvested fish species were noted. Twelve samples of various DSCS were collected for use in genetic studies.

During each dive, scientists surveyed depths ranging from approximately 150 to 350 m and observed hard bottom substrates that consisted of cobbles and mixed-size boulders scattered across the seafloor. Generally, the greatest variety and abundance of DSCS species were observed in a depth range between 200-290 m, and typically occurred on steeply sloping to vertical ridges and boulder faces. Across sites, the most abundant coral species observed included octocorals preliminarily identified as *Calcigorgia* (later identified in the lab as *Swiftia sp.* with one individual turning out to be *Anthothela* sp.) and *Paragorgia* on rocky substrata, and *Balticina* on soft substrata. In some locations, there were large patches of corals belonging to the genus *Swiftia*. On two occasions, individual *Primnoa pacifica* colonies were observed both on and off transect, growing on the side of large boulders. On the steepest of ridge faces the stony coral colonies of *Lophelia pertusa* (=*Desmophyllum pertusum*) were observed and often adjacent to many, and sometimes very large, individuals of *Desmophyllum dianthus*. Generally, when hard bottom was present (from cobble to tall ridge faces), scientists most commonly observed flat plate, finger, barrel, and vase sponges. The fish species most frequently encountered included rosethorn, sharpchin, redbanded, greenstriped, and yelloweye rockfishes, thornyheads, as well as many halibut and other flatfish species. Spiny dogfish, pink urchins, box crabs, sea stars (including *Pycnopodia helianthoides*), and seapens were also encountered fairly frequently over sandy mudflat and cobble substrates.

Figure 7. Images from the ROV *Beagle* that highlight some of the rocky habitat encountered at the site called Rainbow Ridge North in the Olympic Coast National Marine Sanctuary.

2.3.4 Next Steps

Analysis of video transects by SWFSC has helped to systematically quantify fish, sponge, coral, and invertebrate species metrics within and adjacent to 'Olympic 2 EFHCA' – the only EFHCA area overlapping OCNMS. DSCS observation records are expected to be submitted to the DSCRTP national database by the end of 2023. Information from this effort contributes to the effective management of living resources and habitats found within OCNMS and will help inform an upcoming formal review of the sanctuary's 2011 Management Plan. The effort also provided valuable information about the condition of benthic habitats to partners from the Makah Tribe and Quileute Tribe, who co-manage fishery resources in the portion of the sanctuary where these ROV surveys occurred.

2.4 Research Cruise to Channel Islands National Marine Sanctuary on the R/V *Shearwater*: 2019 (SW-19-06)

2.4.1 Background and Objectives

A 2019 expedition in the Channel Islands NMS built upon previous efforts referred to as 'Patterns in Deep-Sea Corals' that took place from 2015-2017 (Caldow et al., 2015; Etnoyer et al., 2017). The research team embarked from Santa Barbara, California aboard NOAA Research Vessel (R/V) *Shearwater* with MARE's ROV *Beagle*. The dates of operation spanned June 4-15, 2019 and the objectives were to explore newly mapped deep-water habitat around CINMS, ground-truth these maps, and evaluate the distribution of mesophotic DSCS and fishes in relation to surficial geology. Specifically, this expedition sought to accomplish the following:

1) Survey mesophotic and deep-sea coral ecosystems in priority areas identified by partners.
2) Explore newly mapped deep-water habitat around CINMS from previous cruises.
3) Evaluate the abundance and distribution of DSCS and fishes in relation to geology.
4) Collect live biological specimens of deep-sea corals for live display and husbandry at the Monterey Bay Aquarium.
5) Deploy temperature sensors for synoptic monitoring of temperature from 20 to 182 m.

2.4.2 Approach

The science team consisted of deep-sea coral biologists from Deep Coral Ecology Lab (DCEL), an aquarist from MBA, and fishery experts from SWFSC. ROV dives were planned in advance using multibeam bathymetry and backscatter maps to pick areas of hard and soft bottom. Each dive consisted of a series of pre-planned transects that surveyed presumed hard and soft bottom habitats observed in the mapping data. Transects were intended to be 5-15 minutes duration but could be longer (20 minutes or more). During transects, the ROV traversed different substrate types which allowed analysts to assess the abundance of structure forming invertebrate individuals/colonies per 100 m^2. DSCS analyses were conducted in DCEL by NCCOS analysts and fish analyses by SWFSC analysts. In between transects, biological specimens were collected with the ROV's manipulator arm and a scoop. Once specimens were retrieved on the deck of the ship, they were placed in a cooler and maintained alive with chilled surface water for live husbandry by Monterey Bay Aquarium.

Four sets of two HOBO® TidbiT MX® temperature loggers were deployed, each set with one logger activated via Bluetooth communication and one logger that was set to log-only mode to ensure the maximum battery life of 10 years. Each logger was set to record temperatures every 30 minutes. The tandem logger sets were deployed at 20, 50, 106, and 182 m around Anacapa Island on a line with a bottom weight and a float wrapped in reflective tape to assist in future recovery.

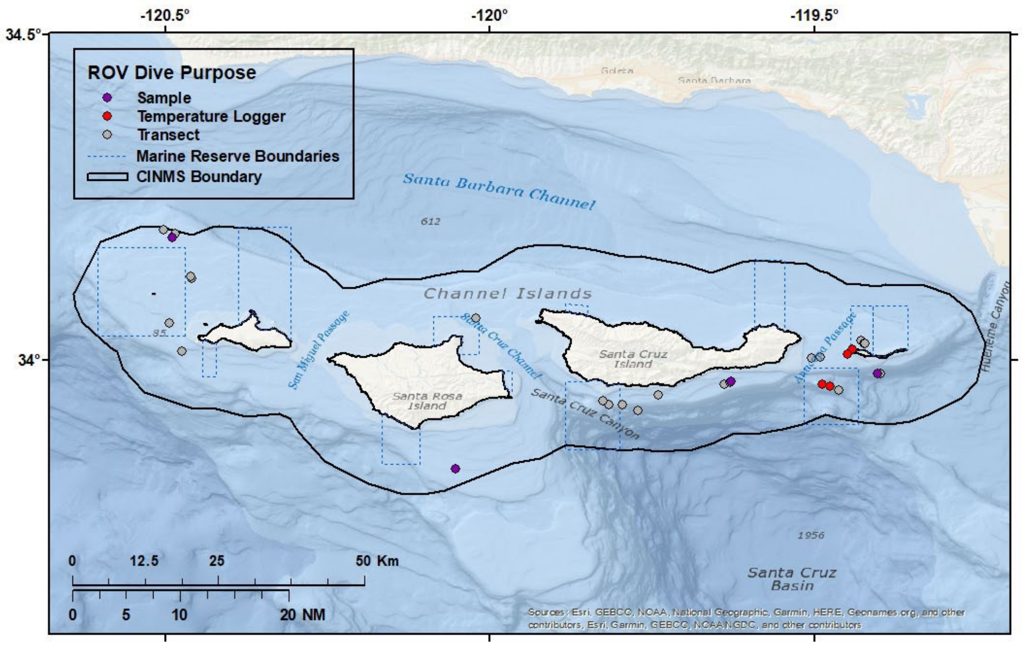

Figure 8. A map showing the ROV *Beagle* dive locations where scientists surveyed mesophotic and deep-sea coral ecosystems in the Channel Islands National Marine Sanctuary.

2.4.3 Significant Results to Date

The expedition explored sites off all four northern islands (Figure 8) within CINMS (Etnoyer et al., 2020). A total of 30 ROV dives were conducted during the expedition, yielding a total bottom time of 32 hours and a linear distance surveyed of 30 km. Depth ranges explored during the dives ranged from 18-415 m. In total, 69 seafloor transects were conducted and ranged between 54-915 m in length and at depths ranging between 34-404 m. A total of 12 biological specimens were collected during the expedition. Specimens collected included ten corals, one squat lobster, and one sea urchin. All specimens were maintained alive on the ship by Matt Wandell to support his studies for an aquarium exhibit of deep-sea corals at MBA. Paired temperature loggers were deployed at 106 m and 182 m on Footprint ridge and two at 20 and 50 m on the northwest side of Anacapa Island. The loggers were deployed at established monitoring stations previously reported in Gugliotti et al. (2019). For more information about this expedition, see Hennige et al. (2020).

Figure 9. Images from the ROV *Beagle* highlighting various rockfish and soft coral species observed during an expedition in the Channel Islands National Marine Sanctuary. Photo credit: MARE and NOAA.

2.4.4 Next Steps

Given the mandate to preserve and maintain this unique marine environment, natural resource managers require a detailed understanding of the distribution, abundance, and condition of the benthic habitats in the sanctuary. This expedition contributed to an ongoing effort to validate new seafloor mapping data and eventually produce a benthic habitat map for CINMS. Data will also be used to assess the relationship between habitat-forming DSCS, fishes, and surficial geology. All DSCS observations were submitted to the DSCRTP National Database, and fish observations will be submitted in 2023.

2.5 Research Cruise in Monterey Bay National Marine Sanctuary on the R/V *Fulmar*: 2020

2.5.1 Approach

Visual surveys in Sanctuary Ecologically Significant Areas (SESAs),[9] Central California Marine Protected Areas (MPAs), and recently modified (e.g., closed or reopened) EFHCAs were conducted to better understand the occurrence and status of DSCS within the Monterey Bay NMS. Targeted sites represent a poorly characterized depth range within the sanctuary: deeper than standard SCUBA diving depth and shallower than most ROV work. The objectives of this project were to conduct image-based surveys within EFHCAs and MPAs with a video lander to determine and characterize the occurrence of DSCS in depths ranging from 40-350 m.

2.5.2 Significant Results to Date

Despite unseasonable winds and swell, successful sampling days were conducted on October 7th, 9th, 10th, 15th, 16th, and 17th. The first objective to collect high-definition imagery data within SESAs, EFHCAs, and California MPAs was completed using a Benthic Observation Survey System (BOSS) video lander (Figure 10A). Scientists conducted 113 BOSS video lander drops in depths that ranged from 84 to 345 m across six sampling days (Figure 10B). Test drops in sandy

[9] NOAA National Marine Sanctuaries. 2016. Sanctuary Ecologically Significant Areas (SESAs) Quick Look Reports - MBNMS. [Available at https://montereybay.noaa.gov/research/techreports/trmbnms2016.html]

areas were not included in the data analysis. Of the 113 drops that occurred in EFHCAs, 26 occurred in MPAs and 50 in SESAs. Some interesting species caught on video include a Big Skate (*Raja binoculata*), a Blue Shark (*Prionace glauca*), brachiopods (*Laqueus* spp.), Orange Cup Coral (*Balanophyllia elegans*), and a Giant Pacific Octopus (*Enteroctopus dofleini*). During the cruise, over 40 fish species were identified from the imagery. This number will likely increase as the second objective is underway to characterize the occurrence of DSCS and their associates.

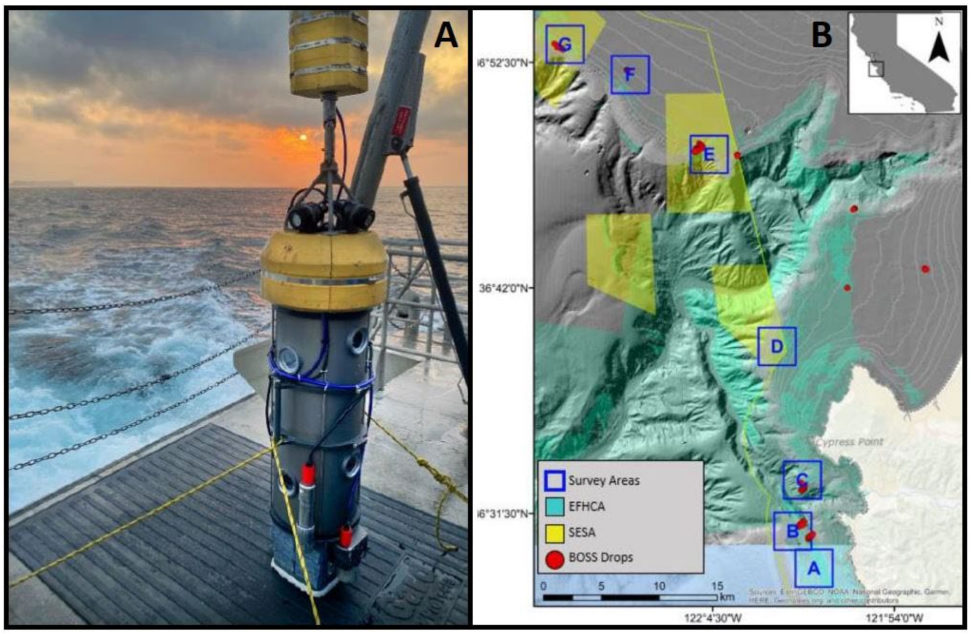

Figure 10. A map of the survey areas A-G (blue boxes) ranging from the shelf edge off Santa Cruz, CA to a deep ridge off Point Lobos. Benthic Observation Survey System (BOSS) video lander (instrumentation shown in the image on the left) drops are represented by red points, Essential Fish Habitat Conservation Areas (EFHCA) are represented by turquoise shading, and Sanctuary Ecologically Significant Areas (SESA) are shaded in yellow.

2.5.3 Next Steps

Further video analysis is ongoing using EventMeasure (SeaGIS, Australia) to systematically identify fish, sponge, coral, and invertebrate species. Observation records are expected to be submitted to the DSCRTP national database in 2023, accompanied by a full cruise report. Information from this effort will contribute to the effective management of central California sanctuaries, in addition to providing preliminary baseline data on areas subject to regulation changes that may be used to assess the magnitude and impact of local benthic disturbances over time.

Section 3: Field Research Projects Funded Partially by WCDSCI

3.1 Research Cruise in Cordell Bank, Greater Farallones, and northern Monterey Bay National Marine Sanctuaries on NOAA Ship *Bell M. Shimada:* 2018 (SH-18-09)

3.1.1 Approach and Significant Results to Date

Sanctuary scientists and partners completed mapping and visual surveys of deep-sea habitat in Cordell Bank, Greater Farallones, and northern Monterey Bay NMS on July 30 - August 10, 2018. With partial support from WCDSCI, the mission aimed to collect data on seafloor habitats and communities that could inform sanctuary management. The three main objectives were to:

1) Survey areas in the RCAs and EFHCAs that were proposed by PFMC to be opened to commercial bottom trawling in 2020 (80-200 m).
2) Explore and characterize new areas on the continental slope from 200-600 m.
3) Revisit areas that had been explored previously for more detailed characterization, including specimen collection and monitoring.

The work took place from Bodega Bay to Año Nuevo, CA onboard NOAA Ship *Bell M. Shimada* and used MARE's ROV *Beagle*. In addition to sanctuary scientists, the collaborative project included personnel from NOAA NCCOS, Office of Coast Survey (OCS), MARE, USGS, California Academy of Science, Greater Farallones Association, and Marine Conservation Institute. Approximately 300 km^2 of mapping data were collected. Using the ROV, 15 dives were completed totaling 47 hours of seafloor video along 83 transects at depths of 37-625 m, including continental shelf soft sediment habitat, rocky reefs, steep continental shelf, and bank features (Figure 11). Thirty-one specimens were collected for identification, including some specimens that are new observations for the sanctuaries. The surveys conducted within the RCAs and EFHCAs proposed for regulation changes were the first to assess these areas since they were closed in 2005. Prior to 2005, a camera sled survey was conducted in CBNMS in 2004 on the shelf in an area that later was designated as EFH.

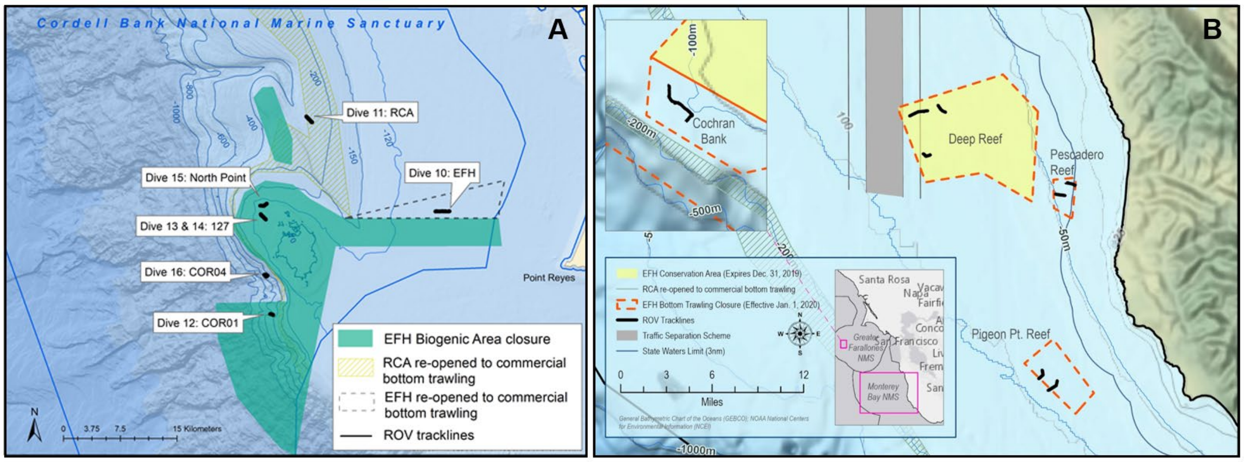

Figure 11. Maps of the dive sites conducted within (A) Cordell Bank and (B) Greater Farallones and Monterey Bay National Marine Sanctuaries. Both maps highlight areas newly closed to fishing per Amendment 28 to the Groundfish Fishery Management Plan in green (CBNMS) and red dashed outlines (GFNMS and MBNMS).

Other highlights included an observation of a sixgill shark, the northernmost observation of a stony colonial coral (*Coenocyathus bowersi*) and a new observation of a gorgonian coral (*Eugorgia rubens*), in addition to abundant and diverse fish and invertebrate communities. Data collected within CBNMS, GFNMS, and northern MBNMS have been analyzed and provided to DSCRTP and a report on the CBNMS sites[10] has also been published.

3.2 Research Cruises to National Marine Sanctuaries on the US West Coast on E/V *Nautilus*: 2020

3.2.1 Background and Objectives

The Ocean Exploration Trust is a non-profit organization established in 2007 that supports national and international deep-sea exploration with support from federal, private and public sector donors. The NOAA Ocean Exploration has closely partnered with OET since 2009, funding some of the exploration and outreach work conducted on their Exploration Vessel (E/V) *Nautilus*. In 2018, through funds from ONMS, OET supported research and public engagement in sanctuaries along the West Coast. The depth range of OET's tandem ROV system (*Hercules* and *Argus)* alongside their skilled exploration corps and advanced telepresence system have provided opportunities for audiences at home and abroad to explore sanctuaries in real time while simultaneously gathering critical data needed for effective sanctuary management. This partnership has been instrumental in addressing sanctuary research and management priorities related to deep-sea resources and has resulted in novel discoveries, while engaging large audiences ranging from the general public to the next generation of explorers.

[10] NOAA National Marine Sanctuaries. 2020. Characterization of Cordell Bank, and Continental Shelf and Slope: 2018 ROV Surveys. [Available at https://cordellbank.noaa.gov/science/publications.html]

3.2.2 Approach and Significant Results to Date

During WCDSCI, OET's E/V *Nautilus* was independently conducting deep-sea exploration and research along the West Coast and was not directly guided or funded by this initiative. However, to build on the momentum gained during WCDSCI and supplement missed NOAA Ship opportunities due to the COVID-19 pandemic, the initiative worked with sanctuary chief scientists in 2020 and funded the analysis of relevant E/V *Nautilus* cruise data collected in areas with overlapping science and geospatial priorities.

The 2020 field season was unlike any before it due to the multitude of safety precautions taken to reduce the risk of COVID-19 transmission. OET minimized the total number of crew and outside scientists aboard the E/V *Nautilus* and relied heavily on their telepresence system to conduct remotely-led fieldwork. For the sanctuary-led legs in the Olympic Coast, Monterey Bay, Channel Islands, and nominated CHNMS, the majority of the 24/7 operations were led from the chief scientists and designated watch leads' homes and offices. With watch shifts lasting four hours each, six remote shifts needed to be filled during a standard 24-hour ROV dive, unfortunately without the convenience and comforts of sailing with the shipboard team. Filling a remote shift required the leads to find a quiet space while in a work-from-home situation, take care of their own meals, install and troubleshoot new software for communicating directly with the ship, and assemble their own stations with multiple monitors and reliable, high-speed internet. These circumstances presented challenges but also an opportunity to increase the number of experts actively participating in each sanctuary's mission, broadening the larger scientific community's engagement in sanctuary specific work and the initiative.

One proposed and three established sanctuaries were explored across three different legs (Figure 12). Extraordinary collaboration and organization by ONMS, WCDSCI, and OET led to the participation of 28 different watch leads that guided sanctuary ROV operations over multiple weeks of fieldwork. All leads were briefed on WCDSCI and sanctuary priorities, objectives, and methodologies so they could determine sample targets, guide transects, take notes, and engage the public audience on sanctuary topics. Scientists from WCDSCI and EXPRESS led portions of the expedition and included experts from NWFSC, SWFSC, ONMS, and USGS. The flexibility, determination, and positive attitudes of all involved were critical to the success of these missions.

Though the goals for each sanctuary differed slightly, there were several overarching objectives shared between sites:

1) Conduct visual surveys consisting of quantitative transects to identify and characterize DSCS and associated communities.
2) Explore previously unsurveyed areas to gather baseline or preliminary characterization information, or survey previously explored areas to gather information on DSCS assemblage changes.
3) Collect samples for species identification, genetic, and stable isotope studies.
4) Collect 3D photomosaics for sanctuary science and outreach products.

WCDSCI funded the image annotation of the quantitative transects conducted within sanctuaries (and one proposed sanctuary), the development of 3D photomosaics for sanctuary education and outreach products (Section 5.1), and the processing and analysis of coral and sponge samples for genetic studies (Section 4.7). In several sanctuaries, samples for other partners related to EXPRESS priorities and beyond were collected as well. For example, OET collected samples requested by USGS of DSCS, seawater, and sediment from OCNMS, CINMS, and the proposed CHNMS for stable isotope analyses to characterize deep-sea food webs.

Individual sanctuaries also addressed site-specific priorities and/or leveraged other opportunities within each leg. For example, OCNMS co-led NA121 with Dr. Andrew Thurber (Oregon State University). ROV work during this leg balanced visual surveys and collections in deep canyon features within the sanctuary and the exploration of biological communities associated with methane seeps and the site of a known meteorite fall outside the sanctuary. Both GFNMS and MBNMS co-led NA122 where ROV surveys were conducted in previously unexplored areas of Pioneer Canyon (located within northern MBNMS, but administered by GFNMS), as well as near Davidson Seamount where survey targets included large aggregations of brooding octopus, a whale fall, and an unexplored area south of the well-studied seamount. CINMS and ONMS West Coast Regional Office staff co-led NA123 and balanced survey priorities between newly mapped but previously unexplored areas located offshore Point Conception in the proposed CHNMS, namely Santa Lucia Bank and fault scarp, as well as within CINMS inside several of the MPAs.

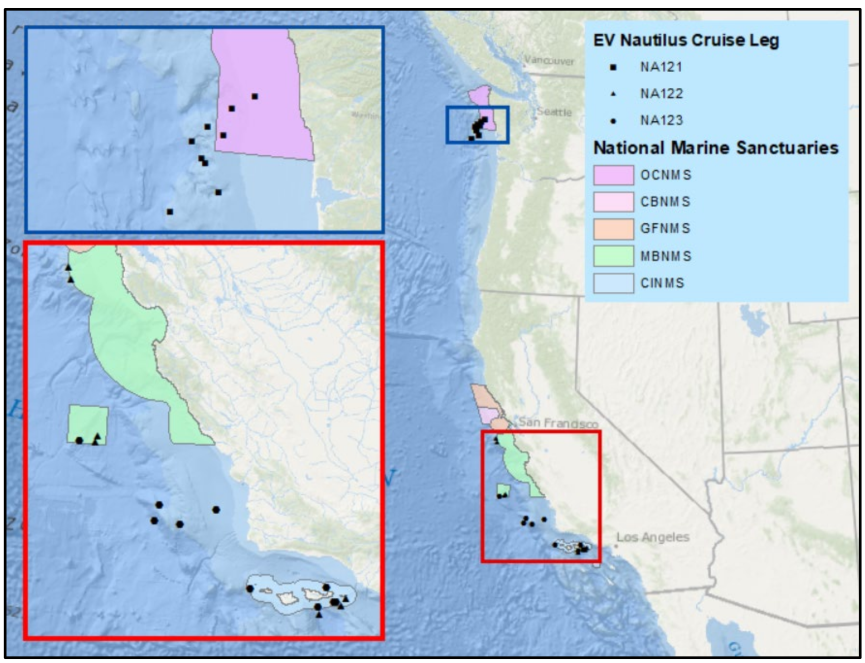

Figure 12. A map of ROV dive locations across Ocean Exploration Trust's 2020 E/V *Nautilus* field season that were led or co-led by National Marine Sanctuary scientists.

Twenty-six dives were completed, 393 samples were collected, and 10,806 km^2 of the seafloor was mapped between the three E/V *Nautilus* expeditions led or co-led by sanctuaries (Table 3).

Table 3. EV *Nautilus* cruise metadata for the legs led or co-led by sanctuary scientists in 2020.

Dates	Expedition	# Dives	# Specimens collected	Mapping km^2
20 Sept-1 October	NA121: OCNMS and Oregon State University	9	149	1,506
7-15 October	NA122: Central California (GFNMS/MBNMS)	7	85	10,300
16-26 October	NA123: CINMS & Santa Lucia Bank	10	159	0
Total	*>300 hours ROV bottom time*	*26*	*393*	*10,806*

Highlights from OCNMS (NA121) included visual surveys and biological samples from communities in and around deep canyon features near the Quinault Canyon, partly within the sanctuary and also within the 'usual and accustomed' harvest areas of the Quinault Indian Nation and Gray's Canyon south of OCNMS. ROV work focused on the exploration of DSCS, fish habitats, and surveys of organisms associated with more than 2,000 methane seep and hydrate locations identified in the region over the past decade.

Highlights from GFNMS and MBNMS (NA122) included two 24-hour dives at Pioneer Canyon that revealed a variety of habitats ranging from gently-sloped, soft sediments with sea pens and benthic fish, to steep rocky terrain with numerous bamboo and bubblegum corals, and large delicate glass sponges. The first 22-hour dive at Davidson Seamount characterized approximately 15 acres of a small volcanic cone hosting extensive aggregations of brooding octopus mothers in addition to revisiting a whale fall last documented in 2019 which was surprisingly more decomposed than expected. Lastly, an 18-hour dive was spent in an unexplored region southwest of Davidson Seamount where the seafloor consisted of a variety of basalt formations, including pillow lava, vertical walls, and high rugosity.

Highlights from exploration in the CINMS and proposed CHNMS (NA123) include four dives off Point Conception near the Santa Lucia Bank and escarpment, and seven dives within the CINMS. The long and deep dives (some >3000 m) off Santa Lucia Bank revealed interesting geological features of the bank and large, abundant colonies of several coral species, like bubblegum and primnoid corals. The last dive before moving to CINMS was a site identified during the 2018 EXPRESS cruise as a potential petrale sole spawning area (Powell et al., 2022). petrale sole is an important commercially harvested species on the West Coast and researchers recorded many observations of the flatfish, sometimes in 'piles' on the seafloor. Dives within CINMS were much shallower and explored areas like the Richardson Rock Marine Reserve where large assemblages of commercially and recreationally important rockfish species were encountered. The most exciting and unexpected discovery occurred during a dive in deeper areas of the Footprint Marine Reserve where researchers came upon an expansive rolling landscape of mostly dead glass sponges of the genus *Farrea*. Subsequent to the initiative, the NOAA DSCRTP provided funding for a 2021 AUV survey at this site to characterize and map this unusual habitat and to make a preliminary assessment of whether it could be a glass sponge reef.

Sanctuary staff also participated in several education and outreach programs during the field season. Hosted by OET, sanctuary chief scientists from each leg participated in the video series "Next on Nautilus" to highlight and explain the goals and objectives of each mission. Explore by the Seat of Your Pants, an organization that connects classrooms virtually with scientists from all over the world, hosted live interactions with the chief scientists as well to teach students about NMS exploration as well as about conservation and general science and technology career paths. Lastly, during a subset of dive that were live-streaming during the day, OET staff connected local teachers with the ship and remote watch leads so classrooms could ask questions in real time.

For more detailed information about the E/V *Nautilus* expeditions to West Coast sanctuaries in 2020, see this ONMS web story[11] and the 34th Oceanography Supplement,[12] which highlight the missions.

3.2.3 Next Steps

All ROV transect video from these 26 dives has been annotated by analysts at SWFSC. Observation records from these data will be submitted to the DSCRTP database in 2023. Biological samples collected for ongoing genetic and taxonomic studies funded by WCDSCI have been archived at Harvard Museum of Comparative Zoology, while samples for local sanctuary partners, such as the Santa Barbara Museum of Natural History and CAS, have been archived at the requesting institutions. Samples collected for ongoing stable isotopes studies conducted by USGS have been shipped to project PIs. All ROV video and associated environmental data from this 2020 and other *Nautilus* missions can be requested from OET. Video footage from the 2020 field expedition is also archived and publicly accessible on YouTube.

ROV *Hercules* video of seafloor communities collected off the Washington coast is available for review by members of the State Ocean Caucus as they utilize the Washington Marine Spatial Plan, approved in June 2018, to evaluate a proposed offshore wind project near Grays Harbor (south of OCNMS).

Overall, missions such as these contribute to the larger effort of characterizing new habitats and providing initial baselines for monitoring the status and trends of the living and non-living resources within sanctuaries to inform effective management and conservation. The majority of deep water habitats within West Coast sanctuaries have yet to be explored and characterized. Each mission that produces visual survey data such as the 2020 E/V *Nautilus* missions will be used in sanctuary condition reporting, as mandated by Congress, and used to inform management decisions.

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[11] NOAA National Marine Sanctuaries. 2021. Fathoming the Deep: Increasing Our Understanding of Deep-Sea Ecosystems in West Coast Sanctuaries. [Available at https://sanctuaries.noaa.gov/news/jan21/fathoming-the-deep.html]

[12] Oceanography. 2021. New Frontiers in Ocean Exploration. [Available at https://tos.org/oceanography/issue/volume-34-issue-01-supplement]

3.3 Research Cruise to Cordell Bank, Greater Farallones and northern Monterey Bay National Marine Sanctuaries on the R/V *Fulmar: 2021*

3.3.1 Approach and Significant Results

A joint cruise between Cordell Bank and Greater Farallones NMS was conducted to survey seafloor habitat in CBNMS, GFNMS, and northern MBNMS and was completed on August 30, 2021, totaling 12 days at sea. The overall objective was to collect quantitative data to support sanctuary management. This included exploring new areas, quantitative surveys in areas that are subject to fisheries management regulations or are vulnerable to human disturbance, and to monitor areas for environmental change.

The mission investigated Pioneer Canyon, Farallon Escarpment, Cordell Bank, and nearby shelf and slope habitat. Using the MARE ROV, the team completed nine dives, collected two biological samples, and collected visual images along 46 quantitative transects to aid in assessing the status and trends of habitats and species in the sanctuaries (Figure 13). Scientists from GFNMS, CBNMS, partners from California Academy of Sciences, Greater Farallones Association, and USGS participated in the cruise. Data analyses and reports are anticipated to be complete in 2023.

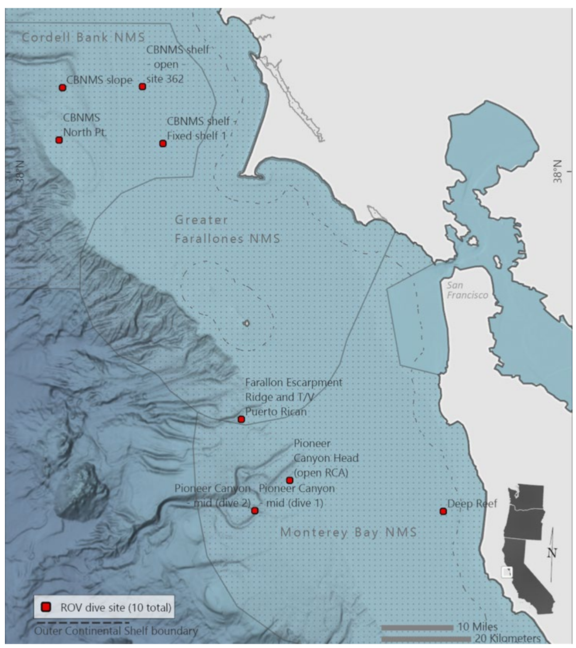

Figure 13. A map of dive locations of the 2021 cruise on the R/V *Fulmar* in northern Monterey Bay, Greater Farallones, and Cordell Bank National Marine Sanctuaries.

Section 4: Associated Studies

4.1 Prioritizing Areas for Future Seafloor Mapping, Research, and Exploration Offshore of California, Oregon, and Washington

4.1.1 Background and Objectives

Spatial information about the seafloor is critical for decision-making by marine science, management, and tribal organizations. While this type of information is important, its collection is expensive, time consuming, and logistically intensive. Developing a network of partners and coordinating data needs can help overcome these challenges by leveraging collective resources to meet shared goals. To help promote coordination across organizations, NOAA NCCOS developed a spatial framework, process, and online application to identify common data collection priorities across space. The approach has been used at the national level by the Interagency Working Group - Ocean and Coastal Mapping in support of the National Strategy for Ocean Mapping, Exploration, and Characterization (NOMEC).[13] For the WCDSCI, the application was used by organizations participating in WCDSCI and EXPRESS to identify overlapping, high priority areas for seafloor mapping, sampling, and visual surveys offshore of California, Oregon, and Washington.

4.1.2 Approach

To identify priority areas, the West Coast was divided into five subregions and 3,265 square grid cells approximately 10x10 minutes (~14x18 km) in size. In addition to this spatial grid, existing relevant spatial datasets (e.g., bathymetry, protected area boundaries, etc.) were compiled to help participants understand the location of existing seafloor information and data gaps and to identify areas they wanted to prioritize for future data collections. An online application was developed using Esri's Web AppBuilder to house this spatial grid and relevant spatial datasets. Twenty-six participants from federal, state, tribal, and academic organizations entered their priorities in this online application, using virtual coins to denote their priorities. Grid cells with more coins were higher priorities than cells with fewer coins. Participants also reported why these locations were important and what data types were needed. Results were analyzed and mapped using statistical techniques to identify significant relationships between priorities, reasons for those priorities, and data needs.

4.1.3 Significant Results

Ten high priority locations were broadly identified for future mapping, sampling, and visual surveys based on the results of the prioritization. These locations were distributed throughout the West Coast, primarily in depths less than 1,000 m, including areas offshore of California's Ventura, Santa Barbara, San Luis Obispo, Monterey, Marin, Sonoma, Humboldt, and Del Norte Counties, Oregon's Curry and Lincoln Counties, and Washington's Grays Harbor County

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[13] NOAA. 2023. The National Ocean Mapping, Exploration and Characterization (NOMEC) Council. [Available at https://www.noaa.gov/ocean-science-and-technology-subcommittee/national-ocean-mapping-exploration-and-characterization-nomec-council]

(Figure 14-A). Participants consistently selected (1) Exploration, (2) Biota/Important Natural Area, and (3) Research as their top reasons (i.e., justifications) for prioritizing locations. Participants also consistently selected (1) Benthic Habitat Map and (2) Bathymetry and Backscatter as their top data or product needs in high priority grid cells. Cluster analysis revealed that responses could be grouped into four important general types (Figure 14-B). One cluster was comprised of nearshore areas, which are important for nautical charting and coastal hazards assessments. Another included areas at the boundaries of tectonic plates in the region. A third cluster highlighted areas less than 1,000 m deep that are of high value for fisheries, marine conservation, and research. The last cluster was comprised of locations with active or proposed energy leases. When applied, this information can answer five basic questions that are important for planning fieldwork (i.e., where, when, what, who and why) enabling NOAA WCDSCI, EXPRESS, and other organizations to more efficiently leverage resources and coordinate their mapping of high priority locations.

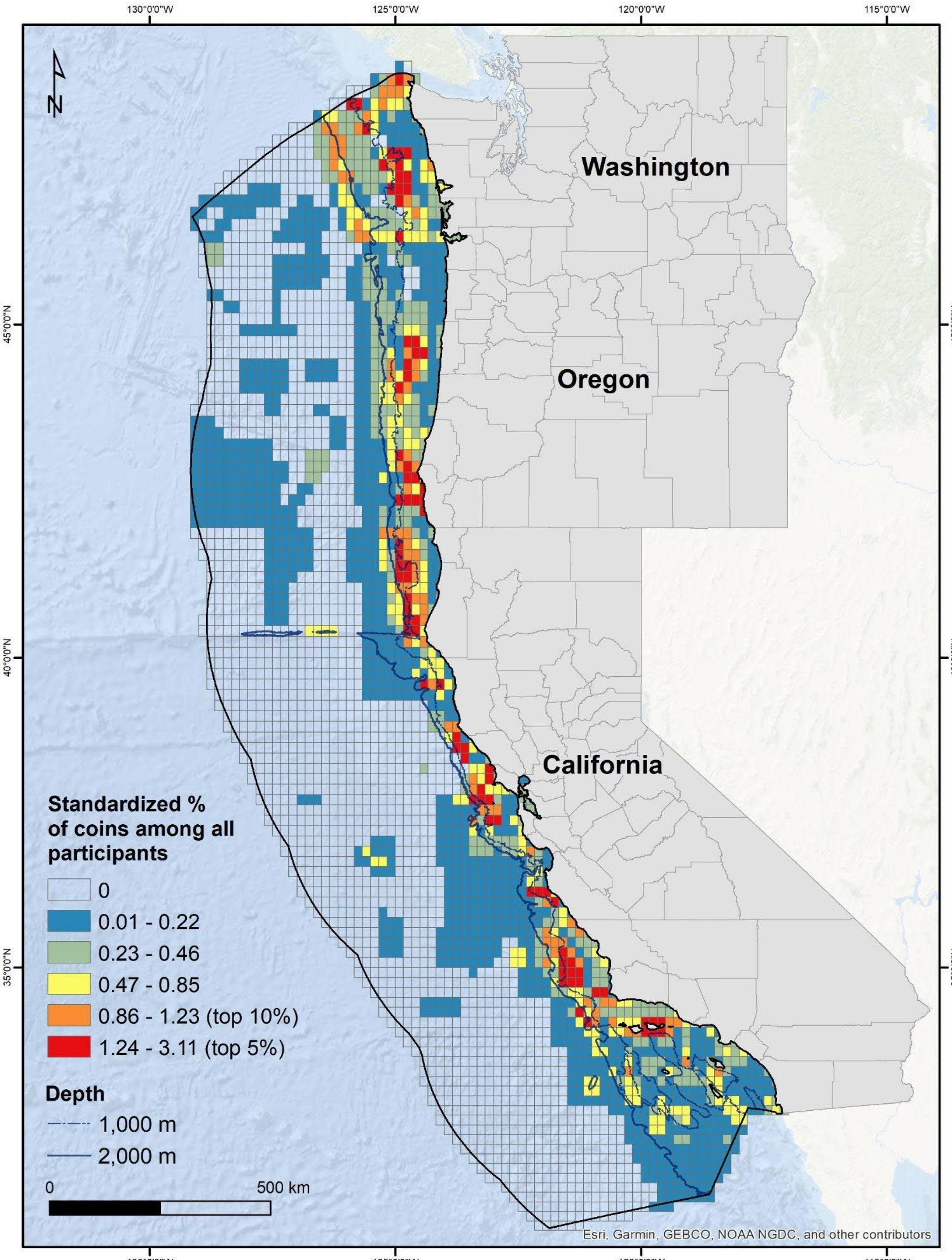

Figure 14-A. A map showing the standardized percent of coins allocated in each grid cell for the US West Coast. Cells with the top 5% and 10% of coins denote the highest priority for participants. From Costa et al. (2019).

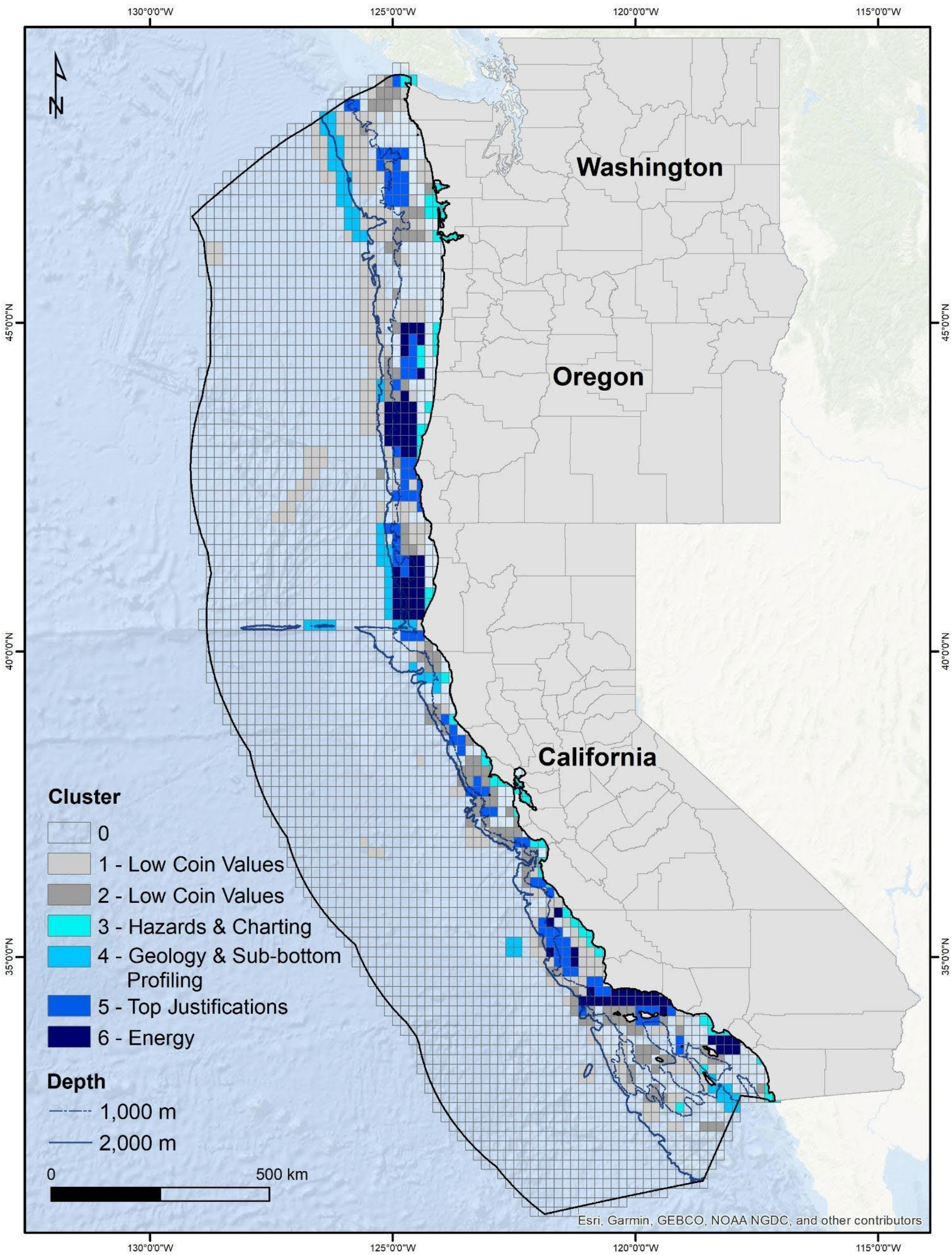

Figure 14-B. A map showing clusters of similarly attributed cells, based on the standardized percent of coins for each justification and product. From Costa et al. (2019).

Three main products were developed for this project: (1) a report describing the process, analysis, and potential applications of data and information developed during this spatial prioritization effort (Costa et al., 2019), (2) geographic information systems (GIS)-ready datasets depicting the seafloor mapping and visual survey priorities for the 26 participants, and (3) an online digital atlas to make these results broadly discoverable and accessible. These products are all publicly available from the NCCOS project webpage,[14] and selected layers are being updated through the EXPRESS data viewer[15] maintained by USGS.

4.2 Image-based analyses of 'coral gardens' in Channel Islands National Marine Sanctuary

4.2.1 Background and Objectives

This study was an image-based analysis of old and new image data, and a continuation of benthic surveys since 2015 entitled 'Patterns in Deep Sea Corals'. The focus of the work was to document and define 'coral gardens', as aggregations with higher than average density on a particular substrate type. The project used pre-existing video from 2017, and acquired new video from 2018 and 2019 (Section 2.4). The objectives were to assess coral density, to compare this to OSPAR guidelines of one colony/m^2 over an area of 100 m^2, and to limit the transect areas to a single substrate – hard, mixed, or soft. This effort refined previous approaches that used five and 15 minute time intervals as the unit of measure.

4.2.2 Approach

NCCOS DCEL in Charleston, SC developed new video-based annotation techniques to process these data as continuous video and as periodic still images. The project employed federal staff (Etnoyer), contracted staff at CSS, Inc (Shuler, Gugliotti), an undergraduate student (Penn) from Millersville University attending the National Science Foundation-funded summer program in Research Experiences for Undergraduates at College of Charleston, and another undergraduate (Will) from Nova Southeastern University in Charleston as a NOAA Hollings Scholar. The NOAA-led team worked together with the MARE team to participate in benthic ROV surveys aboard R/V *Shearwater* in 2018 and 2019. The new surveys were combined with a dataset from NOAA Ship *Shimada* in 2017, with the same teams. Detailed cruise reports were prepared, for DCEL led cruises, to assist the data analysts in their annotations (Etnoyer et al., 2020; Etnoyer et al., 2021).

Analysts were asked to work with video first, and then with stills. Each yields a different type of information at a different rate. The video transects yield a continuous uninterrupted image sample, with an accurate count, but the image quality is degraded. The still images provide a periodic subsample that does not yield a comprehensive count, but the strobe lighting gives crisp

[14] NOAA National Centers for Coastal Ocean Science. 2019. Prioritizing Areas for Future Seafloor Mapping, Research, and Exploration Offshore of California, Oregon, and Washington. [Available at https://coastalscience.noaa.gov/project/prioritizing-areas-for-future-seafloor-mapping-research-and-exploration-offshore-of-california-oregon-and-washington/]
[15] USGS. 2023. EXPRESS Data Viewer. [Available at https://geonarrative.usgs.gov/expressdataview/]

detail that allows better assessment of size and injury. Both techniques document the presence and absence of biology and geology. However, the video is 30 frames/second, and the stills are one frame, approximately every five seconds. The differences in detail and periodicity require different techniques to achieve comparable results. These were detailed through standard operating procedures and annotated R-code for map visualization.

The video transect information was designed to yield density values over a single substrate, and then be submitted to the National Database. Density values were accomplished through second-by-second annotation from the moment the ROV is on-bottom to the moment it is off bottom. The estimation uses an R script for 'rolling density values', a moving window technique that operates over a spreadsheet, to find continuous segments (rows) of like substrates between 30 and 100 m^2 in area, and then quantify the density of corals and sponges within that segment. The annotation output yields a .csv file with parameters for area swept, geology, and biology. The script visualizes a continuous dive track as a gradient of consolidated to unconsolidated substrates, with intermittent occurrences of gorgonians, sea pens, black corals, and sponges (see Figure 15).

The still images replicate abundance, substrate, and position but they contain more information on colony size and health that is ancillary to transect data. Information on health and condition is difficult to acquire and control. The level of detail with images is promising, but the work is time consuming. Some types of information are subjective, e.g., what is a good 'highlight' image? Objective measures of size and health can also be hard to reproduce. They require lasers to be present for scale, and software like PhotoQuad. Then, to verify the accuracy of these assessments, it is advisable to use multiple reviewers.

These techniques are still in development at DCEL. The effort continued throughout 2021 with funding and support from NCCOS, using the VIAME toolkit (available from Kitware) with multiple annotators at DCEL, to test the reproducibility of counts, species identifications, and health scores in a machine-learning environment. New automated approaches are both feasible and highly desirable from the perspectives of science and management.

4.2.3 Significant Results to Date

This project produced new reports, new datasets for the NOAA National Database, new reproducible methods for image annotation, and standard operating procedures with R Code. The cruise reports from *Shearwater* 2019 and *Bell M. Shimada* 2017 are publicly available online (Etnoyer et al., 2020; Etnoyer et al., 2021). The datasets were submitted to the National Database, and are accessible to Sanctuary managers and the public at large. The data can be used to pinpoint high-density aggregations of corals, particularly gorgonian octocorals, within the Sanctuary boundaries. Many healthy coral gardens were discovered in CINMS; 35-40 in total depending on the criteria used to define a coral garden and the spatial scale over which the criteria are calculated (P. Etnoyer, pers. comm.). Given the extent of hard bottom habitat in CINMS, as indicated by backscatter data, the extent of coral gardens may be large.

The project leveraged funding through the engagement of two undergraduate students - Jordan Penn from Millersville University, and Morgan Will of Nova Southeastern University. The students learned new skills and developed new analyses. Their studies produced insightful project reports. Penn's work was able to correlate species occurrence to substrate types. Will's summer work was able to assess size, health, and condition of gorgonian octocorals. Most of the corals were found to be healthy (Etnoyer et al., 2021).

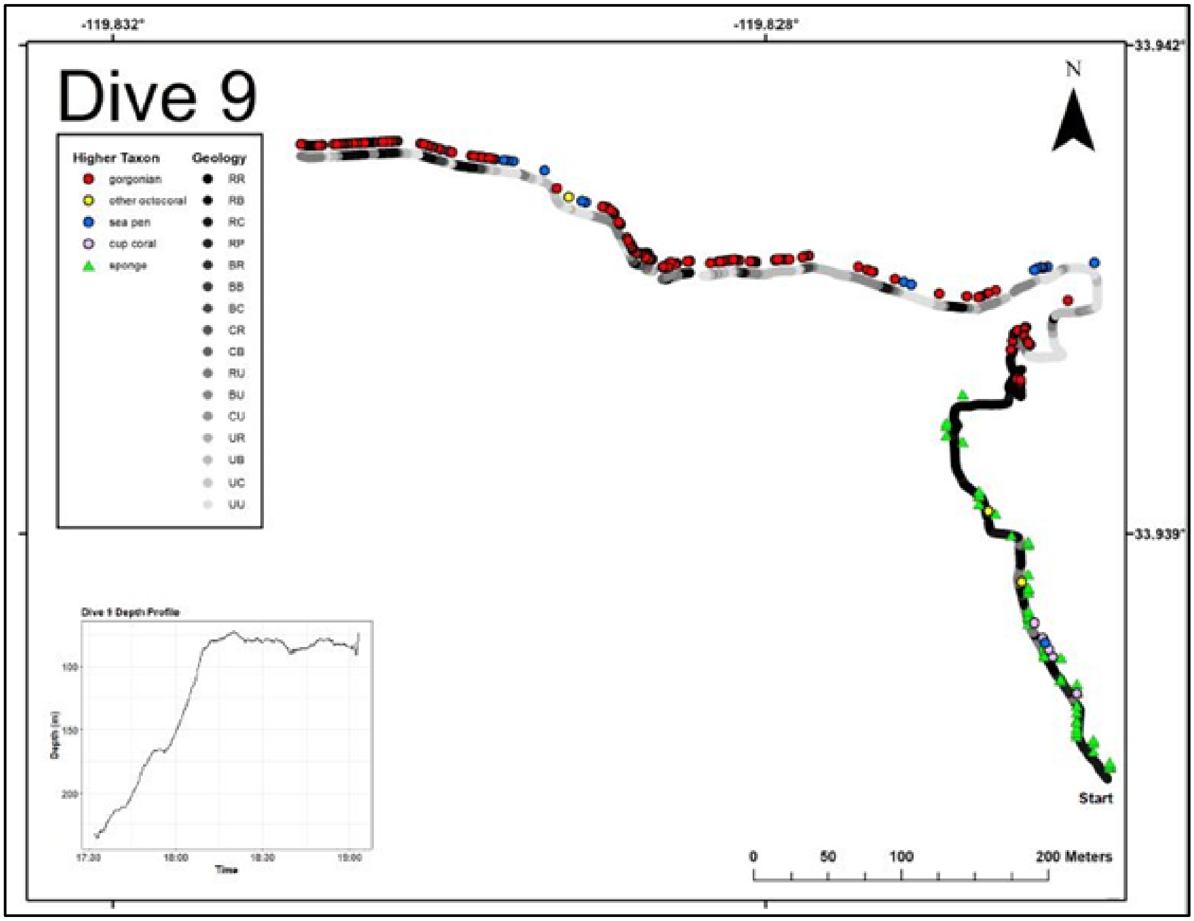

Figure 15. The dive track for Dive 9 aboard R/V *Shearwater* 2019 'Coral Gardens Expedition' showing geological (grayscale) and biological (color) features. This is an example of R scripted output from a second-by-second video annotation technique developed by Elizabeth Gugliotti working in partnership with NCCOS Deep Coral Ecology Lab in Charleston.

4.3 Seafloor Mapping on the US West Coast

4.3.1 Background and Objectives

Seafloor information is critical for decision-making in a number of marine management fields. To date, only a small percentage of the seafloor along the West Coast has been mapped at a resolution useful for understanding the distribution of organisms such as DSCS. To fill these data and information gaps, NOAA ONMS and NCCOS launched the Southern California Seafloor Mapping Initiative (SCSMI) in 2014 to prioritize seafloor areas for mapping in the Southern California Bight. The waters of the CINMS were identified by several stakeholders as high priority, since a number of agencies have jurisdictions and management measures in place around the northern Channel Islands. Since then, the SCSMI has grown into a multi-agency effort called the EXPRESS campaign. This campaign was launched by NOAA, BOEM, and USGS to better coordinate federal seafloor mapping activities from California to Washington. The initiative built on and leveraged these existing initiatives and campaigns to map additional DSCS communities in the region. The projects described below are direct results of investments by the WCDSCI and collaborative efforts across BOEM, USGS, and NOAA to map priority seafloor locations from California to Washington.

4.3.2 Integration of Seafloor Bathymetry on the US West Coast

Over the past 20+ years, various agencies and institutions have used sound navigation and ranging (SONAR) to map the seafloor along the West Coast, including within the CINMS. These surveys have created a patchwork of bathymetry surfaces with different resolutions, qualities, and accuracies, making them challenging for use in broader scale marine management decisions. As a result, NOAA WCDSCI funded NOAA NCCOS to conduct a quality assessment of these datasets, and where possible, normalize and merge them to create unified seafloor bathymetry surfaces for the West Coast. This analysis was also conducted for the other high priority locations identified by the SCSMI and EXPRESS, notably CINMS.

NOAA NCCOS created these unified bathymetry surfaces by integrating over 80 separate bathymetric datasets. On the West Coast, over 20 of these datasets were collected by partners under the EXPRESS Campaign, including OET. These bathymetric datasets were assessed for quality, resampled and merged using tools in CARIS EasyView, ArcGIS and R software, and then used to update two existing bathymetric surfaces created by NOAA NCCOS in 2014 (Poti et al., 2020). The result were two updated bathymetric surfaces (at 25x25 and 200x200 m spatial resolutions) from California to Washington. The remaining 53 bathymetric datasets were concentrated in CINMS. These datasets were collected between 1998 and 2019 by NOAA, USGS, MBARI, California State University Monterey Bay, and OET. These surveys had a wide range of resolutions, qualities, and accuracies since SONAR technology has changed dramatically in the last 20 years. To preserve the highest resolution data possible, several merged bathymetric surfaces were created in CINMS using the same tools in CARIS EasyView, ArcGIS, and R software described above. The resulting resolutions of these surfaces varied by depth from 2x2 m in <40 m, 4x4 m in 36 to 80 m, 8x8 m in 72 to 160 m, 16x16 m in 144 to 320 m to 24x24 m in >300 m.

The outcomes of this project included one updated unified bathymetric surface for the West Coast and five updated unified bathymetry surfaces for CINMS, and contribution to the objectives of the new National Strategy for Ocean Mapping, Exploration and Characterization.[16] While these products are not intended for navigation, they are already being used to inform research and management activities in both CINMS and the West Coast. These applications include informing sampling design, planning for field operations, and identifying remaining key

[16] Ocean Policy Committee. 2020. National Strategy for Ocean Mapping, Exploration and Characterization. [Available at https://www.noaa.gov/ocean-science-and-technology-subcommittee/national-ocean-mapping-exploration-and-characterization-nomec-council/national-strategy-for-ocean-mapping-exploration-and-characterization-nomec/about-nomec-strategy]

data gaps. In the future, these merged products can also be integrated with ground truth data (i.e., bottom video, photography, and samples) to produce spatially-continuous benthic habitat maps to help managers better understand the wide variety and distribution of ecological communities found throughout the CINMS and the West Coast. Currently, no additional bathymetry updates are planned for this project. However, NOAA OCS is building a system through the National Bathymetric Source project to create and maintain high-resolution bathymetry composed of the best available data around the United States, including on the West Coast (Wyllie and Rice 2020). The data synthesized here, and possibly the synthesis itself is under consideration for incorporation into the National Bathymetric Source project.

4.3.3 Advancing the Acquisition of Seafloor Acoustic Backscatter

Marine managers routinely use benthic habitat maps to make decisions about the ocean, its resources, and associated human uses. Acoustic backscatter from multibeam echosounders is critical for developing these habitat maps because it can be used to describe the physical properties of the seafloor, including its hardness and roughness. Roughness and hardness are often correlated with the location of Essential Fish Habitat and deep-sea coral communities. Although backscatter contains critical information for making benthic habitat maps, NOAA and other agencies have struggled to make backscatter acquisition a seamless part of daily operations and standard product deliverables. This challenge is mainly due to a lack of adequate training for hydrographers in the field on the latest standard acquisition practices. To help fill this knowledge gap, the WCDSCI, in cooperation with the SCSMI and EXPRESS, funded NOAA NCCOS to participate in WCDSCI seafloor mapping cruises and help train onboard hydrographers on the best practices for collecting and evaluating acoustic backscatter.

NOAA NCCOS participated in two cruises (2018 and 2019) on NOAA Ship *Rainier* in CINMS. While aboard, NCCOS worked closely with NOAA Ship *Rainier* officers, hydrographers, and crew members to train them on the latest methods for collecting high quality backscatter (Lurton and Lamarche 2015) and to better communicate the acquisition requirements for habitat characterization. NCCOS also collaborated with NOAA Ship *Rainier* and NOAA OCS to find the optimal balance between multibeam echosounders survey requirements for nautical charting and habitat characterization. This effort helped to advance more detailed standard operating procedures for conducting these types of integrated mapping surveys. While there are no additional cruises planned at this time, there is an interest within NOAA to continue developing recommendations for optimizing surveys for both nautical charting and habitat characterization, and designing meaningful quality assessment and quality control procedures for acoustic backscatter. Further developing these recommendations would be beneficial across NOAA, including to the DSCRTP.

4.3.4 Mappers-in-Training Program

The University of Southern California Sea Grant Program (USC Sea Grant) recruited three participants for a Mappers-in-Training Program (MiTP) for a Fall 2018 field study. This program was funded by NOAA OCS, ONMS, and the Office of Marine and Aviation Operations, and conducted in partnership with NOAA WCDSCI, NOAA NCCOS, BOEM Pacific Region, and the EXPRESS Campaign. The MiTP internship was open to enrolled graduate students with research interests in applied seafloor mapping. USC Sea Grant received approximately 50 applications from graduate students from around the United States. From this pool, three graduate students were selected for this internship opportunity from Kent State University, University of California, Davis, and University of California, Santa Cruz. The internship was approximately 11 days long and included two days of orientation at the southern California offices of NOAA and BOEM to brief students on the missions and data needs of these federal agencies. Interns subsequently spent nine days aboard NOAA Ship *Rainier* mapping the seafloor around CINMS. The MiTP provided the opportunity for these students to gain an understanding of how seafloor maps are used by NOAA, BOEM, USGS, and other federal and state agencies to support the United States Blue Economy, and to make informed decisions about our coastal and ocean resources. It also provided the opportunity for the interns to gain insight into ship-board life, obtain experience creating seafloor maps using SONAR systems, and contribute to NOAA's ocean and coastal mapping mission. Towards the end of their time at sea, interns gave short presentations describing what they learned during their experience. No additional MiTP internship opportunities are planned at this time.

4.4 Advancing Deep-Sea Coral Habitat and Distribution Modeling

4.4.1 Background and Objectives

Predictive habitat modeling, hereinafter simply referred to as modeling, is an active area of research, providing a cost-effective means of identifying potential deep-sea coral habitat over large areas that can inform management (Guinotte et al., 2017). Several past and current studies have conducted modeling of deep-sea corals in waters off Washington, Oregon, and/or California (e.g., Bryan and Metaxas, 2007; Huff et al., 2013; Guinotte and Davies, 2014; Poti et al., 2020). Modeling was chosen as one thematic focus for the WCDSCI with specific priorities including advancement of modeling methodology, engagement with management to facilitate use of model products, model validation, and inclusion of important predictor variables.

The modeling work conducted under the WCDSCI had three main objectives:

1) Define good practices for DSCS species distribution modeling for management.
2) Apply good practices to advance modeling of DSCS on the US West Coast.
3) Use data collected through the WCDSCI to validate existing DSCS species distribution models.

4.4.2 Approach

4.4.2.1 Good practices

A technical workshop was convened to define good practices for DSCS species distribution modeling that can guide future modeling efforts and data collection aimed at improving and validating model predictions for management. The workshop was held in Seattle, Washington from February 19-20, 2019 with 20 attendees representing a range of organizations actively involved in US deep-sea coral research, modeling, and management, particularly on the West Coast. Specific topics discussed included: 1) biological and environmental data collection and processing to support modeling; 2) alternative modeling techniques; and 3) application of models for management.

4.4.2.2 Advancing modeling

Many previous models of deep-sea coral distributions in US waters used occurrence data and employed 'presence-only' or 'presence-background' modeling methods (e.g., Bauer et al., 2016; Bryan and Metaxas, 2007; Etnoyer et al., 2018; Georgian et al., 2014; Guinotte and Davies, 2014) including the most recent West Coast regional modeling effort by Poti et al. (2020), although there have been at least a couple of models of presence-absence and abundance data (Huff et al., 2013; Rooper et al., 2014). As discussed at the good practices workshop, presence-background modeling methods entail some challenges and limitations to inference for management purposes. Following the workshop recommendations, this project seeks to advance methodology for predictive modeling of deep-sea coral habitat on the West Coast by exploring alternative techniques that may include presence-absence data, density data, integration of multiple data types (e.g., presence-only, presence-absence, and density), and/or joint species distributions. These alternative techniques are more demanding in terms of data requirements, so this project will focus on a smaller geographic area(s) for which sufficient data are available: one or more National Marine Sanctuaries on the West Coast. Ideally, comprehensive datasets for key environmental predictor variables (e.g., high-resolution bathymetry, backscatter, bottom currents, and ocean chemistry such as organic carbon) will be used. Specific taxa/depth ranges to be modeled and the statistical framework to be used are still to be determined.

4.4.2.3 Model validation

The good practices workshop highlighted the importance of validating model predictions of DSCS distributions, especially when those predictions are to be used for management. A recent West Coast regional modeling study funded through BOEM-NOAA Inter-Agency Agreement M16PG00014 (Poti et al., 2020) provided the opportunity to leverage that study to apply new data collected through the WCDSCI to validate those model predictions.

4.4.3 Significant Results to Date

4.4.3.1 Good practices

The results of the workshop were presented at the 7th International Symposium on Deep-Sea Corals in Cartagena, Colombia (July 29 - August 2, 2019) and were published in an associated special issue of the scientific journal Frontiers in Marine Science (Winship et al., 2020). The conclusions of the workshop will help inform investments in future modeling projects and improve the design of future data collection. More generally, the conclusions of the workshop should be of interest to a wide range of US and international deep-sea coral researchers and managers, and may be relevant to the research and management of other taxa (e.g., other benthic organisms).

4.4.3.2 Advancing modeling

Work on this project to date has primarily involved contacting data holders and managers for National Marine Sanctuaries on the West Coast, particularly Channel Islands, Cordell Bank, Greater Farallones, and Olympic Coast, and assessing data availability, quantity, and quality. Important biological datasets that could support advanced modeling have been identified along with key environmental datasets. Some of the biological datasets were collected/analyzed as part of the WCDSCI and some of the analyses are ongoing. Key environmental data were also developed as part of the WCDSCI (e.g., bathymetry synthesis described in Section 4.3).

4.4.3.3 Model validation

Poti et al. (2020) report on a "proof-of-concept" analysis that was conducted to demonstrate an approach to validating model predictions of relative habitat suitability for DSCS (their Sections 3.2.6 and 3.3.4). The analysis confronted model predictions from regional presence-background distribution models with new data collected with an AUV during the 2018 EXPRESS cruise (Section 2.2). Sampling locations were proposed for model validation purposes, and those locations were considered during survey planning. However, because model validation was not the primary objective of the expedition, a robust, thorough validation of the model predictions was not possible from the data collected. Nevertheless, this analysis demonstrated a statistical framework that can be used to validate model predictions of relative habitat suitability using new data collected opportunistically.

4.4.4 Next Steps

Work will continue on 'Advancing modeling' through the development of predictive habitat models for one or more NMS on the West Coast. Those models will provide new, and hopefully augmented, predictions of the habitat and distributions of deep-sea coral species in the study area(s). Results will shed light on how predictions are affected by the data types considered, potentially improving inferences from existing regional presence-only models.

4.5 Target Species List

4.5.1 Background and Objectives

One ongoing need for DSCS research across disciplines is the collection of additional physical samples. Due to the technological complications of sampling deep-sea organisms, the planning workshop for the WCDSCI identified a need to coordinate among researchers to identify and prioritize species collection needs along with existing sample availability.

4.5.2 Approach

In order to coordinate and identify the need for collections the WCDSCI established and maintained an online Google Sheet, which included fields for species of interest for collection, the names of researchers interested in each species, the purpose of the collection, notations of any permits needed, the geographic location of interest for each collection, and any specific collection notes. The contacted researchers, both within NOAA and at outside agencies and organizations including USGS, the Smithsonian, California Academy of Science, and universities, to identify specific collection needs in the overall deep-coral research community. Contacts were made ahead of each field initiative, with updates and reminders made at the bi-monthly deep-sea coral meetings. One master list was created and maintained through the initiative, and to the present, but over the course of the initiative a number of sub lists were also created and distributed for individual field research efforts, and provided to other research groups including E/V *Nautilus* and the West Coast Groundfish Bottom Trawl Survey (WCGBTS). These additional versions of the list even included putative species images for select taxa to aid targeted collection.

4.5.3 Significant Results to Date

The target collection list was an overwhelming success, facilitating targeted collections throughout the initiative, both through initiative sponsored cruises as well as through partners including OET. A total of 57 coral taxa and morphotypes and 44 sponge taxa and morphotypes were identified as collection targets, of note a number of these requests included multiple species within genera or multiple variations on morphotypes that might represent multiple species. Species targeted for collection included numerous uncharacterized sponges, octocorals needed as DNA vouchers, and species of interest for population connectivity and taxonomy studies. Over the course of the intuitive and in partnership with groups including OET and the sanctuaries, 133 coral and 191 sponge specimens, corresponding to target species, were collected. Work with the collected samples is now ongoing, with samples being sent to museums and outside researchers as well as being directly included in work carried out as part of the WCDSCI. The success of this effort has led to its adoption by groups including OET and the method of establishing a community-wide target sheet with these fields and images is now being utilized as part of their planning for select additional cruises beyond their 2020 fieldwork.

4.5.4 Next Steps

Meredith Everett has continued to maintain and update the West Coast Species Target list in anticipation of any additional collection opportunities in the future. Possibilities include additional collections by the WCGBTS or ROV based collections during anticipated BOEM-funded surveys for potential wind energy siting. As the master list is Google-sheets based it is simple to continue with no additional cost and maintain on an ongoing basis, providing a valuable resource for the deep-sea coral research community.

4.6 Identification Guide for West Coast Deep-Sea Corals, Sponges, and Fishes

4.6.1 Background and Objectives

There is an ongoing need to improve initial identification of DSCS species both from images and samples. While a number of simple identification resources have been developed over the past, many are internal documents, lack detailed descriptions of species, or are out of date with current taxonomy. The ability to have more specific, reliable field-based identification can reduce the need for additional laboratory-based work to confirm species identification and better inform researchers which species will require more specialized techniques for identification. Additionally, more accurate field-based species identification can improve downstream data products such as habitat models, and facilitate targeted collections for additional research such as population connectivity studies. With the ongoing use of visual surveys for habitat and species monitoring, targeted species collection, and the need to identify bycatch, the objectives of this effort are to assemble a comprehensive field identification guide for currently described West Coast corals, maintain an online resource that can allow the maintenance of up to date taxonomic information as deep-sea coral taxonomy improves, and begin to develop online resources that can group unknown morphospecies.

4.6.2 Approach and Significant Results to Date

The goal of this effort is to assemble a comprehensive guide that can be expanded to the entire Northeast Pacific, including British Columbia and Alaska, and prepare both an initial published, paper guide, and subsequently an online resource with additional visual representations of each species, which can be kept up to date as taxonomy and naming conventions for species change. Initial meetings determined which species would be included from the West Coast Deep-Sea Coral Species List (Everett et al., 2022), the format and approximate length allotted to each species, the level of detail included in each description, and what type of visual representations should be included. While descriptions of all species will be included as available, it was determined that initial images should focus on those associated with specific, available collections and samples to avoid confusion, as a number of species can have similar morphology. Images will include *in situ* images (e.g., from ROV or AUV images), specimen images, trawl survey images, and where possible, scanning electron microscope details for species identification wherever possible. Genbank reference numbers to sequence vouchers, as well as museum voucher numbers, will be included where available. In order to account for species with ongoing taxonomic uncertainty, as well as to include sponges, where there is limited taxonomic information available, some groups will be organized on the basis of included genetic information. In these cases, relevant phylogenetic information will be included as well as Genbank identifications (ID) for relevant sequences. In these cases, the species descriptions will be written to higher taxonomic levels, highlighting distinguishing characters when possible or in the case of sponges, simply using the genetic information to group unknown species.

Taxonomic descriptions will be general, written in non-technical language based on and referencing the current taxonomic species description. Where original species descriptions are available through references in the public domain, or through services such as the Biodiversity Heritage Library, links or DOI numbers will be provided. Each species will start on an individual page, and occupy as many pages as needed for a reasonable representation of the visual material available, anticipating 2-4 pages per species.

To date, the ID guide team has been meeting throughout 2020 and 2021. We convened a team of researchers with diverse backgrounds and experience in DSCS and a variety of visual surveys, and included experts from both the US and Canada. Participants in the effort to develop the DSCS field ID guides included Meredith Everett (NWFSC), Tom Laidig (SWFSC), Stephen Cairns (Smithsonian Institution), Merlin Best (DFO), Elizabeth Clarke (NWFSC), Heather Coleman (DSCRTP), Peter Etnoyer (NCCOS), Erica Fruh (NWFSC), Pamela Goddard (Lynker/Alaska Fisheries Science Center [AFSC]), Tom Hourigan (DSCRTP), Christopher Kelly (University of Hawaii), Vanessa Lowe (Lynker/AFSC), Abigail Powell (Lynker/NWFSC), Enrique Salgado (CSS/NCCOS), Andrew Shuler (CSS/NCCOS), Sean Rooney (AFSC), Curt Whitmire (NWFSC), and Rachel Wilborn (Lynker/AFSC). While the original plan was to bring together a group for a few days of in-person meetings to work on the development of the guide, due to COVID-19 travel restrictions all work and meetings were convened online. Meetings were initially held monthly to bi-monthly during initial planning, with additional meetings to discuss individual taxonomic groups, formatting, and content as needed once the group was established. Once the initial layout and content were determined, individual participants began writing up initial species descriptions which were discussed and used as templates for additional species, and an effort began to collect as many species images as possible. These writing and image collection efforts are still ongoing. The team will reconvene to begin formatting and editing once the initial write up of species is complete. Computer resources including high capacity storage drives have been obtained to support collection of images, and this work has also been tied and supported by ongoing genetic efforts to better characterize and distinguish DSCS species.

4.6.3 Next Steps

The next step is the completion of the initial draft write up of the paper field ID guide. This will involve finishing summaries of the species descriptions as well as selecting panels of individual images for each species. Once the text write up is complete, the identification guide team described above will reconvene to review and edit the document and select the final panels of images. Following the completion of the text and initial photo sorting, we will also identify species for which detailed images are lacking, add those groups to ongoing collection target lists (detailed above), and work with outside groups to obtain these images.

Work will then proceed on development of an online resource that can be more easily updated and maintained will also begin. This will involve finding a service such as the National Centers for Environmental Information or the DSCRTP to host these materials as part of their online resources, as well as a plan detailing how periodic updates will be completed. We will work on securing permissions to include photo resources from a wide range of sources.

The final component of this effort will be to build on the work and layouts developed by Howell et al. (2019), as well as in NOAA's Benthic Deepwater Animal Identification Guide,[17] in beginning to summarize morphotypes for species which have been observed, but lack current taxonomic identification and description. The goal of these efforts is to come up with common nomenclature for these groups, as well as sets of identifying characteristics which can be used to designate them, while awaiting taxonomic clarification. These efforts are particularly critical for sponges, where there is a great deal of taxonomic uncertainty.

4.7 Species Identification, Connectivity, and eDNA Studies

4.7.1 Background and Objectives

This initiative supported a variety of genetic and genomics work to better understand the taxonomy and biology of DSCS communities. This work includes DNA barcoding and ongoing development of a genetic voucher collection, application of high-throughput RAD sequencing to better resolve taxonomy and connectivity of West Coast deep-sea coral species, and exploration

[17] NOAA Ocean Exploration. 2019. Benthic Deepwater Animal Identification Guide V3. [Available at https://oceanexplorer.noaa.gov/okeanos/animal_guide/animal_guide.html]

of deep-sea coral habitats using eDNA sequencing. Due to the lack of morphological disparity in some species groups, ongoing taxonomic revisions in some species, and the presence of potential new species and haplotypes, there is ongoing need for the development of genetic vouchers and DNA Barcodes. Additionally, as the importance of sponges as a component of EFH is emerging, there is a need to better identify species and understand their roles as habitat. The establishment of a genetic voucher collection for sponges can help elucidate their taxonomy and support additional work going forward. The sequences established and maintained in a genetic voucher collection for corals and sponges can, in turn, support ongoing eDNA analyses to better understand and document the overall biodiversity in these communities. In cases where traditional molecular barcodes are insufficient to distinguish closely related species, high-throughput RAD sequencing can be applied to develop genome-wide molecular markers to better distinguish these species. This technique can also be applied to study the population connectivity between geographically separated populations of corals on the West Coast, which in turn can better inform the underlying biology of these groups and their capacity for recovery from disturbance. This initiative supports ongoing molecular barcoding of coral and sponge samples collected during fieldwork, as well as additional applicable samples of interest collected as bycatch from other NOAA fieldwork including the West Coast Groundfish survey and collaborative work with DFO. The initiative supported targeted RAD sequencing in three species-groups of interest on the West Coast, to better understand their taxonomy and connectivity, and supported eDNA surveys carried out over the course of all fieldwork to better capture the overall biodiversity of both coral and fish communities.

4.7.2 Approach and Significant Results to Date

4.7.2.1 Molecular barcoding

This initiative successfully added to the DNA voucher collection for West Coast octocorals, and began establishing a DNA voucher collection for West Coast sponges. First pass molecular barcoding has been successfully completed on the octocoral and sponge samples (see below) collected during the 2018 and 2019 EXPRESS expeditions, as well as initial sequencing on select black coral samples and relevant samples collected by the WCGBTS, and sequences are being prepared for archive in GenBank. Molecular barcoding was carried out via Sanger sequencing, using standard molecular barcodes for each taxonomic group. Octocoral samples have been sequenced for the mitochondrial MutS marker, using primers appropriate to each family, select samples were also sequenced for COI and/or 28s. Black corals have been sequenced for the *igrN* locus. The resulting sequences have been compared to the existing DNA voucher collections, confirming species identification for individuals. In select cases, individuals have also been sent to taxonomic experts to confirm species identification. After taxonomic assignment, new species or haplotypes have been added to the voucher collection. Species identifications based on these efforts are being prepared for submission to the DSCRTP database. Additionally, during the 2020 E/V *Nautilus* cruises, the target species list (See section above) was used to facilitate additional collections specifically targeting species gaps in the DNA voucher collection. Over the course of these field efforts, additional black corals, bamboo corals, stoloniferans, *Bathyalcyon*, and deepwater species of primnoids, were successfully collected, and specimens are currently archived at Harvard's Museum of Comparative Zoology. Further molecular work will be carried on these samples over the coming year to expand the molecular barcode database and resolve their taxonomic identifications when necessary.

Field efforts throughout the initiative successfully targeted sponges for collection for the establishment of a voucher collection. Select samples have been sent to taxonomic experts for species identification, however, morphological identification of sponges remains a bottleneck, as the availability of taxonomic expertise in these groups is very limited. To facilitate more rapid identification and the grouping of taxonomic groups lacking additional taxonomic information, we have established a DNA voucher collection for sponges, sequencing them for the standard 28s barcode used for Porifera. We have successfully sequenced 102 sponges to date, with additional sequencing efforts ongoing. A number of these individuals have also been identified by taxonomic experts, but all sequences are being used to cluster similar species into operational taxonomic units that can be associated with specific morphotypes and utilized until clear taxonomic identification can be established or species descriptions written.

4.7.2.2 RAD-sequencing approaches

High-throughput RAD sequencing has been applied to individuals from the *Balticina* (=*Halipteris*), *Swiftia, Chromoplexaura,* and *Plumarella* genera. These efforts have resulted in high-throughput data from more than six Illumina sequencing lanes, resulting in tens of millions of sequencing reads in these species. Analyses of these data are currently ongoing. *Plumarella longispina* individuals sequenced included specimens collected during the 2018 and 2019 EXPRESS expeditions, as well as individuals from the WCGBTS and E/V *Nautilus* expeditions. These data will be used to characterize connectivity among populations of *P. longisipina* from Washington State to the Channel Islands. *Balticina* spp. and plexaurid gorgonians from the genera *Swiftia* and *Chromoplexaura* need taxonomic revision. In *Balticina* spp*.,* the molecular barcodes MutS and COI fail to distinguish the two currently morphologically defined species. Additionally, initial RAD data from ~40 individuals from across the West Coast region, indicated the possibility of two depth segregated species that do not match the morphological descriptions. An additional 105 individuals, spanning the West Coast across multiple depths were RAD sequenced to better characterize this potential update to the species descriptions. Finally, one of the taxonomic groups with the most ongoing uncertainty on the West Coast is the plexaurid gorgonians from the *Swiftia* and *Chromoplexaura* genera. The MutS and COI molecular barcodes fail to resolve a number of species, and morphological identifications occasionally clash with molecular species assignments. One-hundred thirty-two individuals spanning multiple species, collected during the 2018 and 2019 EXPRESS cruises, during E/V *Nautilus* work in 2017, and via WCGBTS have been RAD-sequenced. These data will be combined with existing RAD data from *Chromoplexaura markii* and *Swiftia simplex* (Everett et al., 2016), and the combined data set used to better resolve taxonomic boundaries between plexaurid species.

4.7.2.3 Environmental DNA

Throughout the 2018, 2019, and 2020 field efforts, eDNA samples were collected to support biodiversity surveys along the West Coast. Samples were collected either via Niskin bottles attached to the ROVs used in surveys (1-6 bottles, depending on vehicle) or via CTD rosette, to supplement collection efforts with additional samples or during periods when the ROVs could not dive. One-hundred-sixty samples were collected across all three fieldwork years. Samples were collected across multiple habitats, some in the presence of deep-sea corals, some as background where no corals were present. To date, all eDNA samples have been successfully extracted. Illumina sequencing for deep-sea coral biodiversity has been completed on all samples collected during the 2018 and 2019 seasons, with sequencing of the 2020 collections, as well as sequencing for fish communities associated with these habitats ongoing. While data analysis is ongoing, preliminary analyses have been able to characterize deep-sea octocoral biodiversity across a variety of habitats associated with Amendment 28 EFH boundary changes. Species detected included common species observed during visual surveys, as well as species that went undetected visually and detections of sequence haplotypes that may represent either new species or species missing from the DNA voucher collection developed to date and not currently in online databases.

4.7.3 Next Steps

Next steps in genetic work include additional DNA voucher barcoding, data analysis on connectivity and taxonomy studies conducted via high-throughput RAD sequencing, and ongoing eDNA sequencing and analysis. For DNA barcoding, additional target samples, identified via the targeted collections list described above, were collected during the 2020 E/V *Nautilus* expeditions. OET has archived these samples at Harvard's Museum of Comparative Zoology, subsamples of these collections will be requested from the Museum for molecular barcoding and possible SEM analyses to confirm species identification and add their sequences to the DNA voucher collection. These samples include potential novel species as well as known species missing from the DNA voucher collection. New or clarified species identifications will also be applied to the species ID guide efforts. Initial RAD sequencing for both taxonomy and connectivity studies has been completed and data analyses are ongoing. Individual specimens or additional collections may be added to these data as needed to supplement the existing data. Furthermore, these targeted resequencing efforts will take place in-house at NWFSC on the Conservation Biology genetics lab MiSeq. These efforts may include targeted collections from British Columbia and Alaska to tie data, and connectivity to the ongoing AFSC initiative for select species. Finally, sequencing of all collected eDNA samples will be completed in 2022, with data analyses ongoing thereafter. Additional re-analyses may occur with additions to the DNA voucher collection, but these will be carried out in a targeted manner, utilizing data pipelines developed during the initial analyses. All final analyses will be reported in peer-reviewed publications.

4.8 Comparative Coral and Sponge Associations with Groundfishes in the eastern North Pacific

4.8.1 Background and Objectives

Studies on fish associations with DSCS in the eastern North Pacific have demonstrated mixed results. Studies off Alaska (e.g., Krieger and Wing, 2002; Stone, 2006, 2014; Rooper et al., 2019; Bosley et al., 2020) found high numbers of fish associating with corals and sponges, whereas those at lower latitudes found far fewer associations (Tissot et al., 2006; Yoklavich et al., 2016;

Henderson et al., 2020). The sampling methodology differed between the two areas with Alaskan data coming through visual surveys (drop cameras and ROVs) and bottom trawls while off California, only visual surveys (ROVs and submersibles) were used. These methodological differences notwithstanding, the reason for the fish association disparity between locales remains a mystery. Therefore, the goal of this project was to investigate the relative importance of DSCS as habitat for groundfishes along the US Pacific Coast using existing data sets and comparing methodologies. Such information is central to better understanding the function of these habitats and identifying EFH. This is a two-year study (2020 and 2021) on groundfish-DSCS associations with the first year focused on data from central and southern California and the second year completing a global meta-analysis restricted to temperate and boreal regions, with emphasis along US Pacific Coast and Alaska. In 2020, the primary data set was an extensive, long-term human-occupied submersible data set collected in southern and central California during 2000-2009. This data set comprised 85 dives and 106 dive-transects conducted in central California and 72 dives and 97 transects conducted in southern California. During 2021, the project used two main sources of data: 1) SWFSC's groundfish-DSCS data collected at a variety of scales from both human occupied and remotely operated vehicles visual surveys and from NWFSC's WCGBTS, and 2) ecosystem-specific data synthesized from relevant peer-reviewed manuscripts.

4.8.2 Approach

Fish densities, lengths, diversity, and assemblage structure were compared among similar seafloor depths and habitat types with varying amounts and types of corals and sponges. Comparisons will be made within and between southern and central California study sites at three different spatial scales (<1 body length, <3 m distance, transect) to assess the amount of spatial variability in fish-coral associations. Successful completion of this project will result in quantitative estimates of the relative importance of corals as habitat for a variety of commercially and ecologically significant groundfishes and the spatial consistency of these associations.

The *Delta* submersible (Delta Oceanographics, Torrance, CA) was used to collect video transects of the seafloor. In general, transects lasted between 10-15 min during which time the submersible would maintain a constant speed and height above the seafloor. An experienced scientific observer and a pilot were inside the submersible. The observer would count and estimate the size of all the fishes that occurred within the 2-m wide strip transect. The observer's voice was recorded on one audio channel of the video.

In the laboratory, a video analyst enumerated, identified, and estimated the total length of all fishes. A second video analyst enumerated, identified, determined the health, estimated the height and width, and identified any fish or invertebrate association of all DSCS 10 cm or larger (the same methodology used for all SWFSC video analysis). A fish was considered associated with a coral or sponge if it was within one fish length, while an invertebrate association counted only when an invertebrate was physically touching a DSCS. All data were added to a relational database. For this project, all transects with a fish association were first reviewed for accuracy. During this review, we found some inconsistencies and therefore we selected a total of 105 transects from central California and 97 transects from southern California to watch from beginning to end. Results from this review and previously recorded data were used in the analyses of DSCS and fish association.

4.8.3 Significant Results to Date

Rockfishes were the dominant fish taxa associated with DSCS in both study regions and at both scales. The number of rockfish species with DSCS associations was similar between central (n = 31) and southern California (n = 30). Several other groundfish species (e.g., blackeye goby, painted greenling) and more general taxa (e.g., poachers, sculpins) also were found in association with corals, sponges, or both groups. Flatfish associations were depauperate by comparison but those that were documented mainly used sea pens. Several other fishes that were found in high abundance (e.g., senorita, shortspine combfish) did not have any documented sponge or coral associations.

At a scale of <1 body length, relatively abundant ($\geq$ 50 documented individuals) fishes off central California had generally stronger DSCS associations; however, differences between regions were not substantial (Figure 16A). In both regions, this fauna was composed exclusively of scorpaeniforms, and especially rockfishes. Sponges were more strongly utilized than corals by the studied groundfish assemblages at the <1 body length scale in both regions (Figure. 16A). Gopher rockfish was the only relatively abundant species with an aggregate association percentage of >20%.

In contrast to the one body length scale, relatively abundant fishes (>50 individuals) in southern California exhibited stronger associations with DSCS at <3 m distance than those off central California (Fig. 15B). In both regions, this fauna was composed exclusively of scorpaeniforms and especially rockfishes. Relative use of DSCS was similar at this scale, and more overall associations of both DSCS were noted (Figure 16A, B). Furthermore, coral usage was elevated at the <3 m scale in comparison to the <1 body length scale (Figure 16B). Five species had aggregate DSCS associations of $\geq$30% (e.g., honeycomb and flag rockfishes), all from southern California. The relative proportion of DSCS associations generally was inconsistent among co-occurring species with much more frequent associations reported for some southern California rockfish populations (e.g., bank, halfbanded, pygmy) (Figure 16B).

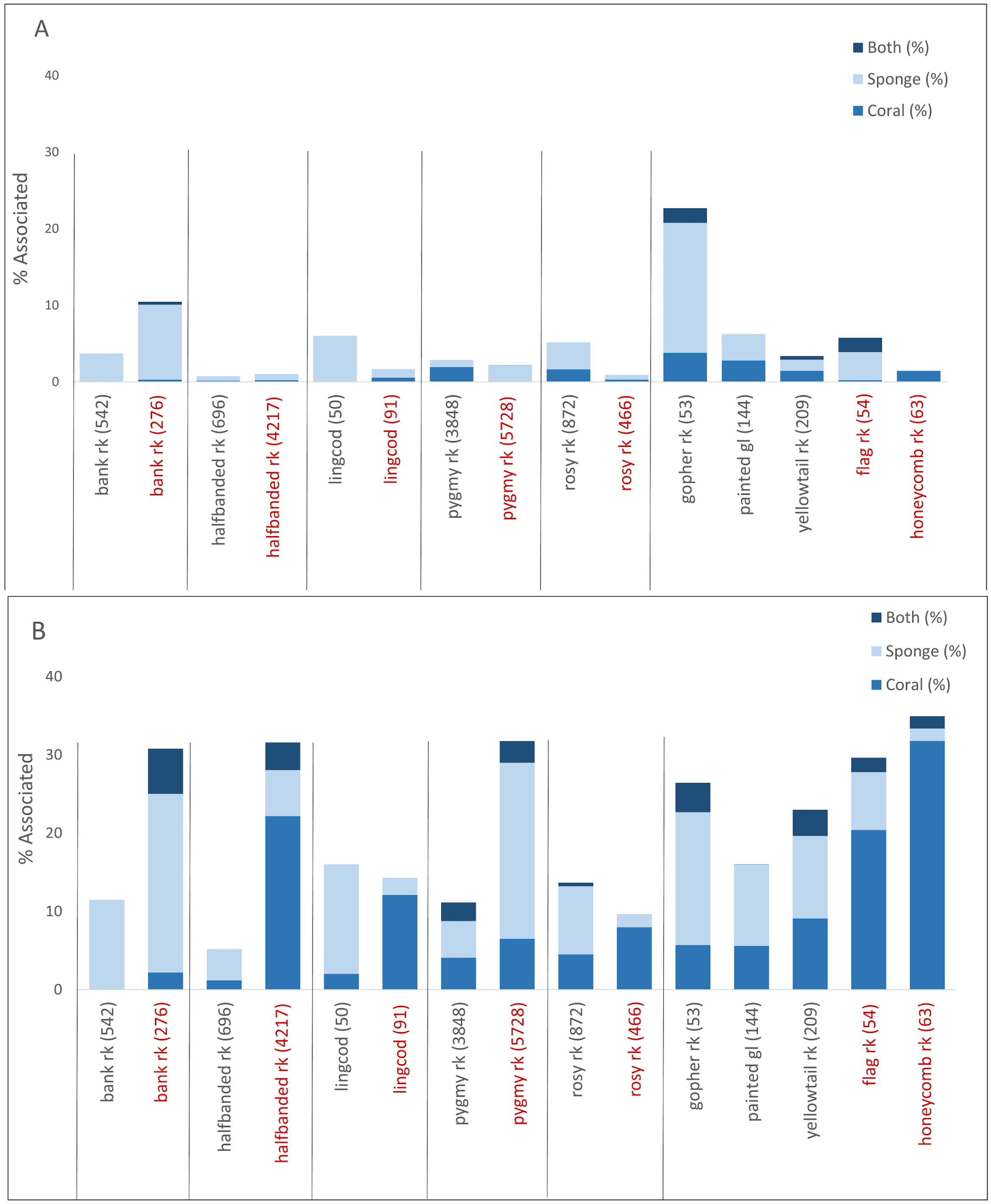

Figure 16. Percentage of groundfishes observed associated with corals, sponges, and both corals and sponges at <1 body length (A) and <3 m (B) scales in central (black text) and southern California (red text), with overall sample sizes of ≥50 individuals. Data are pooled across *Delta* human-occupied submersible transects with sample sizes in parentheses. Abbreviations: rf = rockfish, gl = greenling.

4.8.4 Next Steps

Goals include completing both project components and submitting resultant manuscripts for peer review. Analysis of the central and southern California human-occupied submersible data sets is underway, and we anticipate submitting a manuscript to an appropriate ecological or fisheries journal for peer review and publication. In addition, data compilation and analysis for the global meta-analysis is near completion, with a resulting manuscript slated to be submitted to *Fish and Fisheries* for peer review.

4.9 Historical Data Analysis Projects

4.9.1 Background and Objectives

Research cruises exploring DSCS habitats have increased in numbers over recent years. These cruises collected hundreds of hours of seafloor video. However, either due to personnel availability or funding levels, some video was never fully analyzed for DSCS and fishes. One goal of the WCDSCI was to annotate the remaining video from cruises prior to the initiative onset (2017 and earlier). The WCDSCI committee sent out a data call for how much of this video existed. We received 14 responses of unviewed video files. The committee prioritized the responses and came up with a list, initially funding the highest priority cruises (those that had little DSCS information).

In the first year, the committee funded only a few projects with the highest priorities, but, in the second year, this was expanded to almost all of the prioritized video files from the initial list. The increase was due to COVID-19 because research cruises were canceled for the year and we were not able to complete the last year of fieldwork as we had hoped. The committee redirected the funds from the research cruises to analyzing video from past cruises. Protocols for video analysis were the same for video projects completed by the SWFSC video analysts (including the fish-coral association work, Section 4.8). In addition, sponge samples collected during NA086 (*Nautilus* 2017) were identified by taxonomic experts. Below are the cruises for which existing video was analyzed.

Historical and non-WCDSCI funded video analysis projects that were analyzed during the initiative:

1) *Nautilus* dives from 2016 GFNMS (DSCS, fishes).
2) *Nautilus* dives from 2017 for OCNMS (DSCS, fishes).
3) *Nautilus* dives from 2018 and 2019 at Davidson Seamount for MBNMS (DSCS, fishes).
4) *Nautilus* dives from 2019 at GFNMS (DSCS, fishes).
5) 2012 ROV dives in southern California SWFSC (DSCS, fishes).
6) Twenty-one *Delta* submersible dives in southern California conducted by UCSB from 1990-2010 for SWFSC. Approximately 25% of nearly 100 dives were already analyzed for DSCS.

4.9.2 Cruise Summaries

EV *Nautilus* 2016 - NA077, Greater Farallones NMS
From August 29 - September 12, 2016, the *Nautilus* explored three of the 400 shipwrecks within the extensive maritime cultural landscape of the GFNMS and characterized the deeper regions of the sanctuary through mapping and documentation of DSCS. In addition to exploring several wrecks, scientists also investigated the roles shipwrecks play as marine habitat for fish and invertebrates and explored some of the deepest portions of the sanctuary at Arena Canyon, Farallon Escarpment, and Pioneer Canyon (within MBNMS). Other environmental measurements were taken including eDNA samples and 1,600 km^2 of seafloor was mapped near Arena Canyon, Farallon Escarpment, and Pioneer Canyon. WCDSCI funded data analysis of ROV video of transects in Arena Canyon, Farallon Escarpment, Pioneer Canyon, and on USS *Independence* (Bell et al., 2017).

EV *Nautilus* 2017 - NA086, Olympic Coast NMS
From August 18 - September 3, 2017, OCNMS and NOAA Fisheries explored seafloor resources and features within OCNMS that are associated with three prominent submarine canyons: Quinault Canyon, Quileute Canyon, and Juan de Fuca Canyon. With 16 ROV and 12 AUV dives conducted over 17 days using a combination of NOAA Fisheries' AUV *Popoki* and OET's ROVs, visual surveys were conducted of DSCS communities and associated species, methane seeps, and the wreck of the WWII-era submarine USS *Bugara*. The ship mapped deeper areas of Juan de Fuca Canyon (509 km^2) and Quileute and Quinault Canyons (788 km^2). A unique aspect of this expedition was incorporation of the perspectives of the four Coastal Treaty Tribes that co-manage marine resources in the region: the Hoh, Makah and Quileute tribes and the Quinault Indian Nation. Funding was provided by WCDSCI to analyze video data for DSCS and fishes (Raineault et al., 2018).

EV *Nautilus* 2019 - NA116, Greater Farallones NMS
From October 3-11, 2019, scientists explored the seafloor with remotely operated vehicles in CBNMS and GFNMS during a joint mission. The team completed four dives, two in each sanctuary at the highest priority locations of Point Arena (GFNMS), and Bodega Canyon and Box Canyon (CBNMS). The ship mapped 488 km^2 at Farallon Escarpment. Participants onboard included scientists and educators from CBNMS, GFNMS, California Academy of Science, and USGS. This mission provided science data and products used for management, exhibits, web content, social media content, management and policy, engagement with the public, and helped raise awareness of the sanctuaries. Funding was provided by WCDSCI to analyze video data for DSCS and fishes in GFNMS (support for CBNMS data analysis was not needed) (Raineault and Flanders, 2020).

EV *Nautilus* 2018 and 2019 - NA103 and NA117, Monterey Bay NMS
From October 21-31, 2018, MBNMS and OET personnel were able to conduct only two ROV dives due to equipment malfunction, one of which a 34-hour dive to >3,000 m depth at the base of Davidson Seamount. General cruise objectives included characterizing rocky reef areas and documentation of the distribution and abundance of DSCS and associates, collection of biological samples, and documentation of associations of fishes, corals, and sponges with rocky

substrate. DSCS were observed on a volcanic dome about 230 m in height covered in numerous hexacorals and octocorals. Scientists also discovered hundreds of female brooding octopuses associated with a small volcanic feature to the southeast of the seamount in the last hour of the dive. The second dive occurred south of CINMS due to poor weather in central California. The ROVs traversed a scarp where large sponge reefs dominated the benthic landscape with conspicuous species including *Farrea* sp., *Heterochone* sp., *Staurocalyptus* sp., and species from the family Acanthascinae.

MBNMS and OET returned to this area October 13-18, 2019 (NA117) to further characterize the "octopus garden", explore a ridgeline on the southeastern apron of Davidson Seamount, and to investigate another small volcanic cone. More data were collected on the brooding octopus aggregation, but large geologic features provided substrate for few DSCS and other invertebrates. This long and deep dive revealed a whale fall and another volcanic feature hosting more brooding octopus. WCDSCI funded non-quantitative data analysis to annotate DSCS observations made throughout the long dives (Raineault and Flanders, 2019; 2020).

2012 ROV Dives for SWFSC

In 2012, a visual survey was conducted throughout the Southern California Bight exploring the seafloor and quantifying the presence of cowcod (*Sebastes levis*) using the SWFSC ROV. Surveys covered a wide depth range from ~100-600 m but were only analyzed for the presence of cowcod. These videos were selected to be further analyzed for the presence of DSCS and fishes (other than cowcod). All fishes were counted over all quantitative transects, while only 18 sites were selected for DSCS analysis. These 18 sites represented unique areas (the remaining eight sites were repeated surveys in the same areas). These data added to the spatial coverage of surveys in the Southern California Bight and most sites had not been surveyed for DSCS prior to these surveys.

UCSB *Delta* Submersible Dives 1990-2010

Similar to the 2012 ROV dives, the *Delta* dives covered a wide area in the northern half of the Southern California Bight, including along the mainland and around the Channel Islands. The *Delta* (Delta Oceanographics, Torrance, CA) is a small (4.6 m long, 1.8 m high) two-person submersible. The occupants include one pilot and one scientific observer. *Delta's* maximum depth is 365 m. During quantitative transects, the scientific observer would annotate the video by adding their identifications and thoughts on the right audio channel of the video files. These dives had been previously analyzed for fish species, but had not been examined for DSCS.

Point Conception is considered a biogenic break for fishes and many intertidal invertebrates. It is believed to also be a biogenic break for DSCS, however there is little data to support this theory. Therefore, dives to be reviewed were selected by their proximity to Point Conception and were conducted in areas without previous DSCS surveys. A total of 16 quantitative transects were selected for analysis. All analyzed dives came from nearshore along the mainland from Point Conception to just east of Santa Barbara.

4.9.3 Approach

Video analysis experts reviewed all video footage. Where necessary, dives were split into 15-min transects and the video analysts identified individual DSCS and fishes to the lowest taxa, enumerating, and measuring the maximum width and height of DSCS and the total length of fishes. When available, the digital still images were used to augment the videos to increase identifications of difficult to identify taxa and to determine invertebrate associations. Data on the color, damage, health, upright or knocked over, and fish and invertebrate associations were collected for each DSCS entry. We defined a fish association as any fish within one body length of the DSCS and an invertebrate association was any invertebrate touching a coral or sponge.

For videos collected in MBNMS by the E/V *Nautilus*, analysts counted all DSCS individuals, but did not divide the video into transects or estimate the sizes of species. For the 2016 and 2017 E/V *Nautilus* data from OCNMS and GFNMS, the video analysts created the transects. The analysts selected segments of the dive where the survey ROV was traveling forward in a straight line with the seafloor in focus. If they could not find an uninterrupted 15-min segment, they would piece together smaller length segments until they totaled 15 minutes.

4.9.4 Significant Results to Date

Most datasets were completely analyzed for DSCS. Two datasets (2012 ROV and *Delta* submersible dives) were subset because they each had over 200 transects to analyze. All data sets were sent to the PI of the project for data analysis.

4.9.5 Next Steps

Only three data sets were left to be completed at the end of this initiative (*Nautilus* 2015, 2016, and 2017, all in southern California). All of these were low or mid-priority. In the future, if more funding becomes available, we suggest funding these historical projects.

The next step for each of the funded projects is to statistically analyze the data to determine baseline densities or changes from baseline densities for each of the site locations.

Section 5: Education and Outreach

Despite sustaining impacts from various human activities (i.e. marine debris, climate change impacts, oil extraction, etc.), the vast majority of people are fundamentally disconnected from life in the deep sea. Only in the last several years have scientific and technological innovations permitted scientists to explore and study the deep ocean. In addition, the inability to access or visit such remote ecosystems has resulted in far fewer educational resources and spaces (such as visitor centers) dedicated to deep-sea habitats than their well-studied shallow water counterparts. Thus, in addition to the three targeted projects described below, education and outreach was a more general theme throughout the initiative in effort to provide opportunities for the public to learn and connect with DSCS ecosystems in interactive and engaging ways. For example, the advent of telepresence technology enabled a multitude of ship-to-shore interactions between agency scientists and the public on two of the platforms supported by this initiative, the NOAA

Ship *Reuben Lasker* and Ocean Exploration Trust's E/V *Nautilus*. In addition, whenever possible, communication teams collaborated across agencies to organize social media campaigns and web stories or blog posts. Social media posts across agency profiles shared near-real time findings, interesting photos, and engaging video content while more in-depth web stories and mission logs went into greater detail about missions' objectives as well as the interests and careers of the people behind the scenes. The majority of this content is hosted on the social media and webpages of NOAA Ocean Exploration,[18] NOAA Fisheries,[19] NOAA ONMS,[20] and USGS.[21]

5.1 Photomosaics

Photomosaics are 2- or 3-dimensional (3D), seamless, and interactive models of objects or landscapes. For this project, photomosaics will be created for a number of habitats and targeted coral or sponge assemblages across the West Coast. Mosaics are made of many individual images taken close to the seafloor or an object of interest, such as a swath of the seafloor or a rocky outcrop covered by corals and sponges. The composite image or model has approximately the same resolution and clarity of the individual photos but creates a much larger visual of the benthic community. Mosaics can be used in a variety of scientific and education and outreach products. The interactive nature of the 3D models is particularly engaging in an educational context where the audience can rotate and zoom into the model.

Depending on the data quality, which could be impacted by strong currents, speed of the vehicle, distance to the habitat, total number of images, amount of overlap of those images, water clarity and the technology used to take the photos (ROV or AUV), we aimed to acquire imagery for at least one photomosaic in each of the five West Coast NMS and at other interesting targets outside sanctuary boundaries. These products will greatly enhance the existing West Coast National Marine Sanctuaries Deep Coral Communities Curriculum[22] to help students visualize remote seafloor communities. Completed photomosaics may also be used in other online materials and products, such as web stories and Esri StoryMaps, to inspire and educate a variety of audiences.

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[18] NOAA Ocean Exploration. 2019. Surveying Deep-sea Corals, Sponges, and Fish Habitat off the U.S. West Coast. [https://oceanexplorer.noaa.gov/explorations/19express/welcome.html]

[19] NOAA Fisheries. 2019. Research Cruise to Survey Deep-Sea Corals, Sponges, and Fish Habitat Along the West Coast. [Available at https://www.fisheries.noaa.gov/feature-story/research-cruise-survey-deep-sea-corals-sponges-and-fish-habitat-along-west-coast]; NOAA Fisheries. 2021. Student Interns Take a Virtual Dive into the World of Deep-Sea Corals and Sponges. [Available at https://www.fisheries.noaa.gov/feature-story/student-interns-take-virtual-dive-world-deep-sea-corals-and-sponges]

[20] NOAA National Marine Sanctuaries. 2021. Fathoming the Deep: Increasing Our Understanding of Deep-Sea Ecosystems in West Coast Sanctuaries. [Available at https://sanctuaries.noaa.gov/news/jan21/fathoming-the-deep.html]

[21] USGS. 2019. EXPRESS Expedition Team Hosts NOAA, USGS, and BOEM Leadership. [Available at https://www.usgs.gov/news/express-expedition-team-hosts-noaa-usgs-and-boem-leadership]

[22] NOAA National Marine Sanctuaries. 2023. Deep Coral Communities Curriculum. [Available at https://sanctuaries.noaa.gov/education/teachers/deep-coral-communities/]

5.1.1 Significant Results to Date

During the initiative, photomosaic image acquisition was possible during the 2020 E/V *Nautilus* mission by the ROV *Hercules* as well as during six dives on the 2018 EXPRESS mission by AUV *Popoki*. Photos from five of these dives have been successfully assembled into mosaics by C. Clement at NCCOS and one example is shown in Figure 17 from the south side of Santa Rosa Island. Two slightly different products will be produced depending on the submersible type. For example, the AUV has stereo cameras that look downward and the vehicle is programmed to fly over a relatively flat habitat of interest (Figure 17). Because of the camera angles and autonomous nature of the submersible, the resulting mosaics are more 2-dimensional but can cover quite a large area. However, with an ROV, the cameras and the position of the vehicle can be manipulated to take images at a variety of angles and illuminate the shadows of overhangs and inside crevices, providing bottom-up and top-down perspectives that result in a more 3D photomosaic.

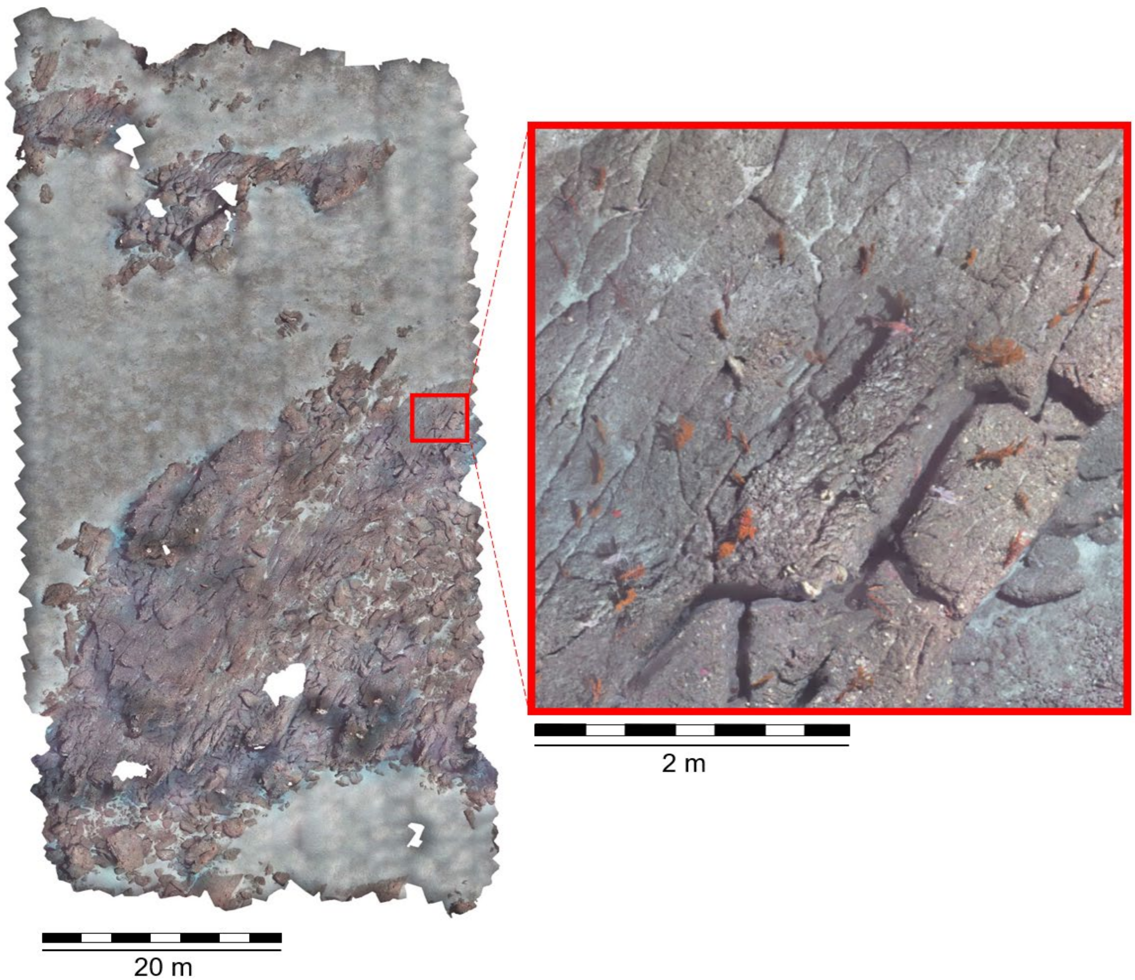

Figure 17. An example of a photomosaic from an AUV dive (roughly 75 x 36 m) during the 2018 EXPRESS mission. This rocky habitat is located on the southern side of Santa Rosa Island in the Channel Islands National Marine Sanctuary.

5.1.2 Next Steps

Imagery gathered in OCNMS, MBNMS, CINMS, and possibly GFNMS from the 2020 E/V *Nautilus* field season will be processed by ONMS personnel in partnership with MBARI in 2023.

5.2 SeaSketch: Interactive Geospatial Portal for Deep-Sea Coral and Sponge Education

West Coast sanctuaries provide protection of living and non-living resources through research and education programs that foster public understanding and stewardship of nationally important marine areas. Sanctuaries develop and implement education programs that target a variety of audiences, from the general public and managers to students. To help fulfill the Initiative's education and outreach related goals, CINMS partnered with the McClintock Lab, creator of the web-based GIS platform, SeaSketch, to develop an educational portal for marine spatial planning and data visualization of DSCS communities.

5.2.1 Approach

Education leads, research ecologists, and SeaSketch data scientists collaborated under the guidance of sanctuary research coordinators and resource protection managers to create a regionally specific SeaSketch DSCS educational portal. SeaSketch is a powerful data visualization tool that can be used by students to examine and solve real world problems. For this project, a regional geodatabase within SeaSketch was created to provide the backbone for student lessons. Teachers and students can view and display the DSCRTP National Database's DSCS observations along with other data layers (e.g., EFH, protected areas, predicted habitat suitability model outputs for various DSCS species, and so on) to challenge students to address hypothetical or real-world management issues. Using SeaSketch, the audience would have an enhanced ability to interact and ask questions about various data layers, the relationships between layers, and to propose evidence-based solutions to local issues related to habitat conservation, ocean acidification, or other resource issues affecting the region. The Seasketch DSCS module will complement and enhance the West Coast National Marine Sanctuaries Deep Coral Curriculum,[22] and its integration will be guided by education and outreach staff from West Coast NMS sites.

5.2.2 Significant Results to Date

A variety of data layers were gathered that were relevant to DSCS habitat conservation. The list was reviewed by sanctuary research and resource protection coordinators before finalized and loaded into SeaSketch. The layers include:

- DSCRTP coral and sponge observations
- Predicted suitable habitat for DSCS (Poti et al. 2020)
- Bathymetry
- Bathymetric Contours
- Benthic Water Temperature (Poti et al. 2020)
- Benthic Substrate Solidity and Type
- Ports or Dredges
- Oil Platforms
- Ocean Disposal Sites
- Submarine Cables
- Offshore Energy Planning Areas
- Shipping Lanes
- Commercial Fishing Effort With Potential Effects on Deep-Sea Coral
- State Water Line
- The US EEZ boundary
- Habitat Areas of Particular Concern
- Rockfish Conservation Areas
- Groundfish Essential Fish Habitat
- Marine Protected Areas
- National Marine Sanctuaries

Once the layers were compiled, CINMS worked closely with education specialists at the Greater Farallones Association to develop an online curriculum for high school students. The lesson plans introduce students to: the web-based geospatial platform, the various spatially explicit data types, as well as how to visualize and interpret the data layers in the portal. Using a subset of the data layers above, the education SeaSketch portal is also able to generate descriptive summaries and reports on the fly using polygons input by the students. The lesson plans then progress through spatial planning activities that challenge students to design, propose, and draw MPAs and exploration missions that address real world conservation issues, such as gaps in knowledge. Students can use the report tool to help justify their proposals.

5.2.3 Next Steps

The draft lesson plans were piloted at a Santa Barbara Unified School District middle school in 2021 to evaluate the accessibility of curriculum, portal data layers, and spatial reports. While initial feedback was mostly positive, several issues were encountered. Issues were related to limited administrative access for teachers implementing new lessons for multiple classes and computational bottlenecks stemming from simultaneous portal access by a full classroom. Currently, further testing of the lesson plans and portal is on hold while SeaSketch undergoes an unrelated, but major update. The next generation of SeaSketch will improve user experience and performance for administrators and project managers. Once the updates are complete and ‘SeaSketch Next’ is fully launched (estimated in early 2023), the issues above will be eliminated or significantly improved, and ready for further evaluation in the classroom.

The lesson plans and educational portal will need to be reviewed by ONMS before becoming available to the public, which is expected to occur in mid-2023.

5.3 3D Digital Images and Printed Coral and Sponge Models

Learning is more effective for students when the content is fun, engaging, and interactive. Existing lesson plans about the deep sea developed by ONMS engages students by asking them to annotate short clips of ROV video transects. Although certainly an engaging activity, the images and concepts of DSCS and other species are digital, 2D, and difficult to interpret with respect to size. One solution would be to acquire DSCS specimens and lend them to teachers and classrooms to accompany their lessons. However, DSCS skeletons and preserved specimens are extremely fragile and difficult to obtain. A more viable and long-term solution, explored here, is to create 3D, digital renderings of real DSCS specimens and to print multiple physical 3D models to share with each of the West Coast sanctuaries and beyond.

5.3.1 Approach

The goal of this project is to create 3D prints of several commonly found DSCS or associates across the West Coast and create education and outreach kits for each of the five sanctuaries. Each kit will be identical and contain one print of each species.

In collaboration with the California NanoSystems Institute, staff at Channel Islands NMS and undergraduates ("workshop wizards") are scanning and printing DSCS specimens at UCSB's Innovation Workshop. The workshop's scanner (EinScan-SP) can scan objects with a maximum length of 30 cm. The scanner comes with a light source, automated turntable, camera, and software for processing and manipulating the digital models. Depending on the size or the morphology of the scanned specimen, the model can be simplified to reduce unprintable textures or shapes, and resized to optimize printing speed and materials. Specimens with certain morphologies are not well suited for scanning if they're too symmetrical, soft (like some sponges), or reflective.

Once the 3D image is ready, the Innovation Workshop has multiple 3D printers that fit the purposes of this project, but given the high accuracy of the Stratasys Objet30 Pro Polyjet printer, most prints will be made using this machine. The Polyjet printer has two printing heads, one for structural material and one for temporary support material for overhanging features. This printer can use rigid, opaque, transparent, or polypropylene resin with a 16-micron resolution. Any temporary support material is washed away using a high-pressure water jet.

5.3.2 Significant Results to Date

To date, ten models of the stony coral *Lophelia* have been printed through the Innovation Workshop: five of a skeleton from the Channel Islands and five of a skeleton from the Gulf of Mexico region (Figure 18). In addition, there is a completed scan of a large cup coral of the genus *Desmophyllum*, loaned to CINMS staff by NWFSC, which is next in line to be printed. In collaboration with staff from each sanctuary, the remaining species will be determined from what specimens are available to borrow from the deep-sea community, such as Harvard's Museum of Comparative Zoology and AFSC.

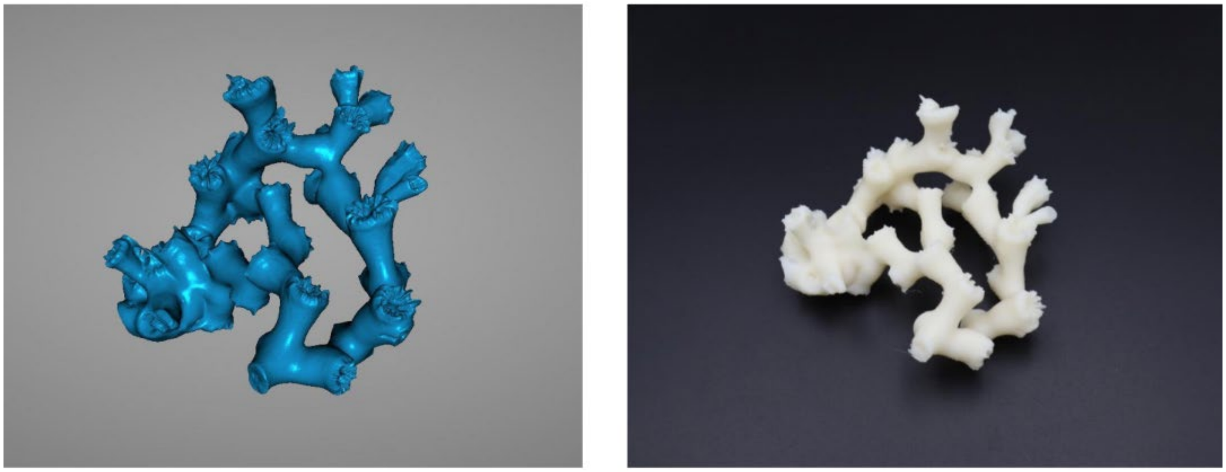

Figure 18. Left: The digital image of the stony coral *Lophelia pertusa* created by the Innovation Workshop using the EinScan-SP scanner. Right: The resulting 3D resin model printed from the digital scan using the Stratasys Objet30 printer.

5.3.3 Next Steps

The final steps in this project are to acquire 3-4 other specimens of DSCS or their associates to scan and print at the Innovation Workshop. Once the prints in multiples of five are complete, each sanctuary will receive one set of each model for educational and outreach purposes (table events, classroom loans, seminars, etc.).

Section 6: Conclusions and Suggestions for Future Research

Across three seasons of fieldwork, WCDSCI further characterized DSCS habitats and their association with fish communities on the West Coast. These efforts included both traditional *in situ* surveys, as well as efforts to analyze existing historical data sets, develop and apply new techniques and models, develop new educational tools, and develop novel products that could enhance future survey efforts. The timing of this initiative, bounding the proposal and implementation of Amendment 28 to the GFMP, provided a unique opportunity to gather baseline data at the time of implementation of new EFHCA management, and can be built upon in the future. This initiative also coincided well with the advent of the 2020 NOMEC Strategy, which calls for coordinating mapping, exploration, and characterization activities. It also enhances opportunities for collaboration among interagency and non-governmental entities with respect to those activities. WCDSCI directly contributed to NOMEC Strategy goals by collecting mapping and exploration data in coordination with the EXPRESS campaign. The initiative contributed important data from the California coast and the Cascadia Margin, both identified as major national priorities for ocean exploration and characterization.

While the initiative timing provided the strategic opportunities characterized above, it also presented unprecedented challenges. The closing years of the initiative took place during the COVID-19 pandemic which curtailed field and laboratory work and prevented researchers from meeting in-person or traveling. Despite this challenge, the initiative was productive, characterizing DSCS habitats coastwide, furthering the understanding of DSCS biology and taxonomy, developing tools and resources that will support future survey efforts, and developing collaborative relationships among agencies and organizations that can support future efforts.

A primary component of the initiative was fieldwork to characterize DSCS habitats across EFHCA boundary changes associated with the GFMP Amendment 28, in areas of relatively high DSCS bycatch, and in National Marine Sanctuaries. Across the region, these surveys included both novel sites, as well as the first opportunity to revisit select sites surveyed during the first initiative to document how these communities have changed over time. This initiative conducted ROV surveys across 20 sites subject to Amendment 28 boundary changes over the course of multiple field efforts. Additional work was done with other systems including an AUV and a video lander to target areas of intermediate depth. These surveys were conducted within new EFHCA closures, as well as areas that have now reopened. Surveys in areas reopened by Amendment 28 preliminarily showed more mud and mixed habitats with smaller individuals and lower densities of corals (2.4 individuals/100 m^2) and sponges (0.4 sponges/100 m^2). Surveys in areas closed in 2020 observed more hard substrata, larger individuals, and greater densities of corals (35 corals/100 m^2) and sponges (12.6 sponges/100 m^2). High density coral and sponge gardens were discovered within the recently closed Mendocino Ridge EFHCA, underscoring the general success of the PFMC's closed area placement. Collection of baseline data in these locations could inform changes to closures/openings of EFHCA areas that may take place in the future, and all data are archived to support future evaluations.

Three areas of relatively high bycatch (as determined by NOAA trawl survey data) were targeted for surveys off southern Oregon and northern California. The two California areas (Brush Patch and Mendocino Ridge, both newly designated EFHCAs) had relatively high coral bycatch while the Oregon area (Sponge Bycatch, not an EFHCA) had relatively high sponge bycatch. Coral densities were above average in the two coral bycatch areas, with Mendocino Ridge having the highest densities recorded during the entire initiative (612.5 corals/100 m^2). The Sponge Bycatch site had a moderately high density of sponges (4.2 sponges/100 m^2). However, most of the observed sponges were small and ROV surveys may have missed the areas of larger sponges caught on trawl surveys. Three banks, Coquille, Daisy, and Santa Lucia, originally surveyed in 2005 were re-surveyed as part of this initiative to assess changes in coral, sponge, and fish density over the interim period. For instance, surveys documented an increase in the number of sponges (~200%), corals (~30%), and rockfish (~56%) on the rocky top part of Daisy Bank, and an increase in the number of flatfish (~800%) and rockfish (~75%) on the muddy flats at the base of the bank. These increases may be related to fishing restrictions that came into effect at this location in 2006.

Initiative surveys also included EFHCA, SESA, and RCA areas within NMS boundaries, newly mapped areas, and areas within the proposed Chumash Heritage NMS. Key findings within the proposed sanctuary included identification of a petrale sole aggregation and a coral garden on Santa Lucia Bank. These data have informed an assessment of boundary alternatives for the proposed sanctuary as well as protection considerations around Rodriguez Seamount specifically, and data collected within the sanctuaries will contribute to ONMS condition reports and management plan revisions. Finally, offshore wind energy siting emerged as an issue of great importance during the initiative, and consequently sites under consideration by BOEM were added to the list of habitat survey priorities in both the 2018 and 2019 EXPRESS campaigns. Work with BOEM to provide relevant data from these surveys is ongoing.

Survey methods developed during this initiative will inform future work in the West Coast region and beyond. Aspects of surveys such as completing multiple dives, quantitative transects and standardized protocols, and collection of specimens and eDNA all contribute to thorough site characterization. This type of documentation can help track changes in habitats and communities over time. Revisiting sites over time, particularly after regulation changes, to evaluate management strategies is also key to understanding the effects of management on sensitive habitats.

The initiative supported additional projects ranging from collections for the larger deep-sea coral research community, to the development of advanced modeling projects, to the rescue and analysis of historical data. These associated activities were both paired with fieldwork (collection targets, eDNA, and imagery collection) and also supported the creation of additional research, management, and education tools and resources (e.g., updated taxonomic lists, ID guides, new models). They also provided projects to "pivot" to in the event of unforeseen disruptions to fieldwork, which proved to be critical due to the impacts of COVID-19. While work on many of these associated studies is ongoing, they will provide additional critical data and resources for future research, management action, and outreach in the West Coast region.

A number of lessons from the WCDSCI are illuminating for potential future research efforts. EXPRESS-driven missions have brought together multi-office, multi-agency efforts to effectively leverage funds from multiple sources, capitalize on ship time, and conduct science in support of priorities from multiple partners. These efforts identified coastwide priority sites for DSCS communities and habitats, marine hazards, and offshore energy development. These successes inspired Seascape Alaska,[23] which brings together USGS, BOEM, and NOAA priorities in the Alaska region. These efforts also drove important collaborations with other agencies including OET, which proved critical to the continuation of work during the COVID-19 pandemic. OET's telepresence facilitated broad participation in the initiative in ROV work, allowing researchers from the initiative to interact with the ship from their homes, allowing targeted sampling and facilitating outreach activities. This also facilitated important survey work in deeper habitats which were identified as a priority during the original priorities workshop, but couldn't be targeted during other field campaigns, and samples collected during this effort will be a critical resource for other activities such as the field guide and voucher collections. The experience gained through this collaboration with OET will help guide future telepresence-based collaboration opportunities on the West Coast, such as the 2023 NOAA Ocean Exploration expeditions currently being planned in the region and in Alaska.

6.1 Priorities for Future Research

With the closure of this research initiative, we have identified a number of remaining gaps and opportunities for further research, listed below. These research needs can be targeted through

[23] NOAA. 2021. Seascape Alaska. [Available at https://iocm.noaa.gov/documents/Seascape Alaska Factsheet_September 2021.pdf]

future initiatives, ongoing research efforts in sanctuaries, ongoing partnerships with NOAA surveys and outside partners or through targeted small projects. Subjects needing further research include the following:

- Human impacts and pressures on DSCS communities, such as those related to climate change (ocean acidification, marine heat waves, and potential changes to ocean circulation patterns)
- Continue resurveying EFHCAs to determine change over time in response to fishing pressure modifications
- Particularly in light of the administration priority to develop offshore energy, survey areas of interest in collaboration with BOEM (wind, minerals, etc.)
- Develop a monitoring program for areas rich in DSCS, as well as within sanctuaries, particularly within the context of human impacts
- Assess how DSCS are connected to humans and the value they bring to communities
- Additional surveys and research in specific habitats
    - Characterize the extent and biodiversity of the unique coral gardens discovered off Mendocino, CA
    - Characterize the potential glass sponge reef discovered in southern California in 2020, determining whether this unique community is actually a true "reef," and what allows it to develop and thrive
    - Explore habitats deeper than 1,500 m coastwide, since technology has limited the majority of surveys to shallower depths
    - Further exploration and characterization of seep habitats and their possible interactions with DSCS communities
    - Continue to monitor Daisy Bank and Santa Lucia Bank for decadal changes in the DSCS assemblages
- Continue characterizing DSCS species and clarifying taxonomy to get a full understanding of biodiversity within the region
- Continue to apply 'Omics tools to DSCS species to better develop genetic resources that can further eDNA applications, characterize species, and inform connectivity across the region
- Mine currently available data for marine debris, a priority identified as valuable to PFMC
- Diversity and inclusion efforts to enhance the next generation of scientists and engineers
- Further investigate the correlation between oceanographic and physical habitat characteristics with particularly dense or diverse DSCS communities

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