Deep-Sea Coral Research and Technology Program: Pacific Islands Deep-Sea Coral and Sponge Initiative Final Report

Michael Parke, Christopher Kelley, Meagan Putts, Virginia Moriwaki, Sarah Bingo, Kelley Elliot, John Smith, Anthony Montgomery, Frank Parrish, Sam Kahng, Amy Baco-Taylor, Brendan Roark, and Daniel Wagner

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Executive Summary

Deep-sea coral and sponge ecosystems are found throughout the U.S. Pacific Islands on the current-exposed slopes of undersea volcanic basalt, drowned reef carbonate, and limited sedimentary features. In some geographic regions of the Pacific Islands, deep-sea corals and sponges are extremely diverse and abundant. Many different species of fishes and invertebrates, and even Hawaiian monk seals, are associated with the communities formed by these animals. While the vast size and great distances between the U.S. Pacific Islands has precluded any comprehensive effort to survey the deep- sea corals and sponges in the region, NOAA's Deep-Sea Coral Research and Technology Program (DSCRTP), in partnership with NOAA's Office of Exploration and Research (OER), enabled a field research program in the Pacific Islands region between 2015–2017 that provided a first look at deep-sea coral and sponge ecosystems in the marine monuments throughout the region, and in other areas of interest such as hydrothermal vents and seeps, isolated seamounts, and mid-water biological and chemical characterization. This report only covers the deep-sea coral and sponge research.

In May 2014, scientists and resource managers representing stakeholders from government, academia, and conservation groups met in Honolulu, Hawaii, to identify critical information needs for deep-sea coral and sponge ecosystems, and to develop a three-year exploration and research priorities plan for the Pacific Islands Region. From 2015 through 2017, the DSCRTP allocated resources used by the NOAA Pacific Island Fisheries Science Center and partners to implement priority research efforts. In 2018, participants at a wrap-up workshop reviewed major outcomes of the 3-Year Pacific Islands Deep-Sea Coral Initiative (PIDSCI) that were completed or still in-progress. The wrap-up workshop identifed ways that the exploration and research results support improved scientific understanding of deepwater biogenic habitats in the Pacific Islands and current or future management information needs, particularly those of the Western Pacific Fishery Management Council and the Pacific Island's Marine National Monuments. Finally, participants identified remaining research needs in the U.S. Pacific Islands region and recommendations for future Deep-Sea Coral Research and Technology Program's partnerships and fieldwork.

Thanks primarily to DSCRTP funds and partnerships with OER and the University of Hawaii, the PIDSCI completed projects in the Pacific Islands region that were identified as priorities in the 2014 planning meeting. These included efforts to: (1) determine what information can be derived from existing data and develop practices to make these and more recently collected data available for future analyses, field work planning, and resources management; (2) characterize the biogeographic patterns of corals and sponges distribution at the basin scale; (3) document the depth distributions of corals and sponges, especially between 500 and 4,000 m; (4) examine the environmental factors affecting the distributions of deep-sea corals and sponges and how these factors might affect biogeographic modeling efforts; and (5) determine the life history traits, genetic factors, and growth characteristics that affect resilience in deep coral and sponge assemblages and influence the ability of and time needed for deep-sea coral or sponge communities to recover from disturbance.

The 2018 wrap-up meeting participants concluded that the OER "Campaign to Address Pacific monument Science, Technology, and Ocean Needs" (CAPSTONE) mission provided a rich set of data that can be mined and analyzed for years to come. The NOAA Ship *Okeanos Explorer* (*EX*) spent 431 days at sea, mapped over 635,000 km², conducted 187 ROV dives at depths ranging from 250 m to 6,000 m, collected 333 primary biological samples (along with many still uncounted commensal organisms), 278 geological samples, actively engaged ~260 participating scientists, students, and managers during ROV dives, and documented more than 16 million views of live video feeds of the expedition. The production of high-resolution bathymetry and backscatter maps of previously unmapped areas of marine monuments in the region is a major accomplishment, and syntheses of these data with existing mapping data from other sources has produced both bottom characterization and geological substrate maps that have informed many research and management efforts. Geological samples should provide new insight into the age of certain communities and the preferred substrate for biological settlement. Biological samples collected during the CAPSTONE fieldwork resulted in the description of multiple new species of corals, sponges, and associates. Collected samples were also critical to taxonomic revisions as well as providing geographical range extensions for many species. As samples continue to be analyzed, further new species discoveries and taxonomic revisions are likely. Ongoing genetic analyses will clarify many taxonomic questions and provide hints to the complex biogeography of the deep-sea organisms in the Pacific Islands. These discoveries will help identify and map vulnerable marine habitats, particularly high-density deep-sea coral and sponge communities, and increase understanding of deep-sea biogeographic patterns of corals and sponges across the central and western Pacific. They also highlight the fact that much is still unknown about the taxonomy and distribution of deep-sea corals and sponges in the Pacific Islands.

The bathymetric, backscatter, and water quality surveys and associated ROV data found that guyot communities were dominated by corals and sponges, both high-density and low-density communities exist throughout the region, coral and sponge community density decreased significantly below 2,500 meters, most corals and sponges were observed in areas of FeMn-encrusted bedrock with low amounts of sedimentation, and significant differences in dissolved oxygen minima values and depths exist throughout the Pacific that are likely effecting basin-wide biogeographical patterns. This comprehensive baseline for biological communities that will likely be impacted by the Mn crust mining industry provides an invaluable dataset for future management deliberations. Despite the wealth of data generated by the CAPSTONE effort, workshop participants agreed that *EX* exploratory dives do not result in evenly distributed sampling with respect to either depth or region. These methods do not lend themselves to quantitative analyses and must be taken into account when evaluating dive data for either biogeographic or depth zonation patterns. Quantitative data analyses continue for projects that were initiated independently of CAPSTONE.

While not completely answering any of our 2014 questions, we have produced new information and gained many new insights that addressed both immediate and future management needs. Future research missions must rely less on extensive cruises and more on statistically-based limited transects and sampling. Data from such study designs can provide more quantitative information regarding taxonomy, connectivity, genetics, species diversity and distribution. Continued and geographically-dispersed in-situ measurements of current flow and other environmental parameters are key to developing better distribution models. More rigorous models would enable us to predict not just locations of deep-coral communities but estimate their vulnerability to disturbance. Deep-sea mining is probably the most imminent threat to the deep-sea coral communities in the U.S. Pacific Islands, and managers would benefit if more information regarding deep-sea corals were forthcoming in the years before the DSCRTP funding rotation returns to the Pacific Islands. New partnerships, new scientists, and new funding are vital to making this possible. Participants acknowledged that limited resources are available to address the wide geographic area of the Pacific Islands Region. Consequently, continued coordination and carefully-targeted activities will be required in order to further our understanding of deep-sea coral and sponge ecosystems in the region.

Acknowledgments

The Pacific Islands Deep-Sea Coral Initiative (PIDSCI) was coordinated by Michael Parke (Pacific Islands Fisheries Science Center Ecosystem Sciences Division). Frank Parrish led the Deep-Sea Coral and Sponge Research workshops and served as lead scientist for main Hawaiian Islands missions. Christopher Kelley served as the primary science advisor to all of the *Okeanos Explorer* field missions, and led the University of Hawaii team (Virginia Moriwaki, Meagan Putts, Sarah Bingo) that performed almost all video annotations, species identifications, and regional site summaries. Bruce Mundy served as the primary fish taxonomist during most dives and hosted many student groups at the IRC viewing center. John Smith consolidated bathymetry and backscatter data for the Hawaiian Archipelago and Johnston Atoll. The PIDSCI advisory panel included NOAA participants from the Office of Habitat Conservation, the Papahanaumokuakea National Marine Monument, and the Office of Exploration and Research, whose scientists planned and led the field missions of the *Okeanos Explorer* and her ROV, *Deep Discoverer*. Other academic advisers included Sam Kahng, Anthony Montgomery, Brendan Roark, and Amy Baco-Taylor. Management advice was contributed by the Western Pacific Regional Fisheries Management Council, and the Natinal Marine Fisheries Service Pacific Islands Regional Office. Additional support for this project was provided by the Pacific Islands Fisheries Science Center.

Hi'ialakai Support for Multibeam Mapping: The project team provided support to the *Hi'ialakai* in preparation for, during, and following HARAMP and MARAMP, including: troubleshooting components of the multibeam systems that were not functioning properly; provide on-going ship-based and software training to the Survey Tech and project team members; coordinate software and hardware vendors and arrange land-based support; provide content for the mission instructions and permits; and conduct a bathymetry coverage gap analysis for the Northwestern Hawaiian Islands, the Pacific Remote Island Areas surveyed during MARAMP, and the Mariana Islands in advance of each relevant mission.

We thank the captains and crew of the NOAA Ship *Okeanos Explorer*. We would like to thank everyone who participated in the remote telepresence broadcasts and provided taxonomic, ecological, and oceanographic expertise throughout the explorations.

We also thank Tom Hourigan, Fan Tsao, and Heather Coleman the NOAA DSCRTP whose support was critical to the Pacific Islands Initiative.

Introduction

The Deep-Sea Coral Research and Technology Program (DSCRTP) was established under the authority of Section 408 of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) as reauthorized in 2007, to identify, monitor, and provide information to protect deep-sea coral areas. The DSCRTP supports exploration, research, and management activities critical to understanding and managing deep-sea corals and sponges. The objectives of NOAA's Deep-Sea Coral and Sponge Exploration and Research Strategy (NOAA 2010) are to (1) locate and characterize deep-sea coral and sponge ecosystems, (2) understand the biology and ecology of deep-sea corals and sponges, (3) understand the biodiversity and ecology of deep-sea coral and sponge ecosystems, (4) understand the extent and degree of impact to deep-sea coral and sponge ecosystems caused by fishing and other human activities, and (5) understand past oceanic conditions and predict the impacts of climate change using deep-sea corals. The DSCRTP has funded a series of 3-year research initiatives in each of the six NMFS ocean management regions.

The U.S. EEZ in the Pacific encompasses more than 5.8 million km^2. The widely spaced U.S. Pacific territories stretch from the main Hawaiian Islands (MHI) in the east, the Northwestern Hawaiian Islands (NWHI) in the north, American Samoa in the south, and the Marianas Archipelago in the west. These territories contain more than 70% of the nations' shallow-water coral reefs that support a diverse and abundant collection of fishes and invertebrates; the vast majority of the area consists of deep-sea environments, punctuated by widely separated emergent or submerged volcanic peaks. Although the prevalence and diversity of deep-sea coral and sponge ecosystems throughout the region is still unknown, limited observations indicate that some areas support extremely rich communities. Factors influencing the abundance and diversity of these communities may include relative proximity to centers of marine biodiversity, age, type, and form of undersea volcanic seascapes, currents, aragonite saturation horizon, and others. Fortunately, throughout the U.S. Pacific Islands, few extractive activities have taken place at depths greater than 500 m, so most of these communities remain intact. However, benthic crusts of the demersal ocean in the Pacific contain significant deposits of precious minerals that are increasing in demand and likely to be targeted for extraction in the near future. Recent expansion of the Pacific Remote Islands Marine National Monument (PRIMNM) and the recent creation and designation of the Phoenix Islands Protected Area (PIPA) as an UNESCO World Heritage site demand correlative investments in exploration and research in order to support science-based management of these areas. Concerns over the future effects of global climate change and ocean acidification increase the need for adequate scientific research to answer questions regarding the response of marine resources to the effects of human-induced disturbances.

One of the main challenges of managing deep-sea coral and sponge ecosystems in the Pacific Islands is that the abundance and diversity of these organisms have not been documented, and are generally unknown, especially at depths greater than 200 meters. Because of the size and scope of the area under U.S. jurisdiction in the Pacific Islands, the vast majority of the area has not been surveyed for the presence of deep-sea coral and sponge communities. In the MHI, the NWHI, and the Line Islands, submersible and ROV dives had recorded abundant and diverse assemblages of corals and sponges down to the operational depth limits of the underwater vehicles used prior to 2015 (< 2,000 m). Since the spatial distribution of these communities is unknown in the U.S. Pacific Islands region, it is difficult to predict the locations and types of human activities that may threaten these ecosystems. Myriad fishes and invertebrates make use of these deep-sea coral and sponge communities; the degree to which they are relevant to shallower ecosystems is starting to be considered. It is understood that many species of deep-sea corals and sponges are found at depths below 400 m, suggesting that future impacts will more likely be the result of activities other than fishing (e.g., deep-sea mining). Deep-water trawl fishing in the 1970s decimated both the pelagic armorhead (*Pseudopentaceros wheeleri*) fishery and the benthic community at Hancock Seamounts, and the fish population has never recovered despite a total moratorium on trawl fishing. The other extractive process that has taken place in the past, particularly in the Hawaiian Islands, has been the harvesting of certain species of deep-sea "precious" corals for use in the jewelry industry.

From 2015 to 2017, the NOAA Deep-Sea Coral (and Sponge) Research and Technology Program funded research on deep-sea corals and sponges in the Pacific Islands region. Research and management priorities for the Pacific Islands were determined through a workshop on deep-sea corals held in Honolulu, Hawaii, in April 2014 (Parrish et al. 2014). Participants at that workshop identified a number of important research questions that needed to be addressed in order to effectively manage these ecosystems throughout the U.S. Pacific Islands, as well as to address the goals of the NOAA Deep-Sea Coral Research and Technology Program. These questions became the guiding priorities for the Pacific Islands Deep-Sea Coral and Sponge Initiative (PIDCSI).

- What information can be derived from existing data sets?
- What are the biogeographic patterns at the basin scale?
- What are the depth distributions of corals and sponges, especially between 500 and 4,000 m?
- What are the environmental factors that affect the distributions of deep-sea corals and sponges?
- What are the life history traits, genetic factors, and growth characteristics that determine how long it takes a deep-sea coral or sponge community to recover from disturbance?

After the completion of the planning meeting in 2014, research proposals were solicited from the PacificIslands deep-sea science and management community. Most of these proposals entailed field work in the main Hawaiian Islands using manned submersibles. Before the start of field and lab research in 2015, the Hawaii Undersea Research Laboratory (HURL) was administratively disbanded by the University of Hawaii, and the PISCES submersibles that were critical to many proposed research projects became unavailable. Through a series of fortuitous events, the NOAA Office of Exploration and NOAA Ship *Okeanos Explorer*, along with her remotely operated vehicle, the Deep Discoverer, were tasked to the Pacific Islands region to conduct the Campaign to Address Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE) for the duration of the Pacific Islands Deep-Sea Coral and Sponge Initiative (2015–2017). This initiative dovetailed nicely with many of the PIDSCI priorities and utilized an unmanned ROV with a depth range to 6,000 meters. Moving from research that had been proposed for a manned submersible with a depth range of 2,000 m to an unmanned ROV fundamentally altered the type of research that could be conducted during the 3-year duration of the PIDCSI. What had originally been proposed as an effort that would provide a detailed examination of the biology and ecology of deep-sea corals in the main Hawaiian Islands was transformed into a Pacific-wide effort to explore the biogeography of corals and sponges throughout the U.S. Pacific Islands area. Despite this change, the PIDCSI initiative attempted to address all of the research questions that had been prioritized at the 2014 planning meeting.

The research was carried out by NOAA scientists from the Pacific Islands Fisheries Science Center, the Papahanaumokuakea National Marine Monument, and the Office of Ocean Exploration and Research (OER), along with partners at the University of Hawaii at Manoa, Hawaii Pacific University, the

University of Texas A&M, the Florida State University, the University of Louisiana at Lafayette, University of Victoria, Smithsonian Museum of Natural History, U.S. Geological Survey, and other international collaborators.

The Pacific Islands Deep-Sea Coral and Sponge Initiative (PIDCSI) mapped and characterized deep-sea coral and sponge ecosystems in select areas of Hawaii and the U.S. Pacific Islands through field surveys that utilized bathymetry and other seascape features to prioritize survey locations. Particular focus of this effort was to determine depth limits and distribution gradients of deep-sea coral and sponge communities and if topographically-induced acceleration of bottom currents is a major driver of community location. As the opportunity and vessel capability arose, the PIDCSI incorporated projects that examined the biology and ecology of deep-sea corals and sponges. It set up a series of sampling stations in established locations in order to determine ages, growth rates, fecundities, and reproductive rates of these organisms as well as prevalent environmental parameters that characterize their assemblages. These projects also included collections of specimens that are being used to resolve questions on the taxonomy and genetic connectivity of deep-sea corals and sponges at different locations of the Pacific Islands Region. Finally, the PIDSCI supported efforts to determine the length of time that deep-sea coral and sponge communities need to recover from anthropogenic and natural disturbances. Throughout this initiative, we (1) advanced NOAA's Deep-Sea Coral Research and Technology Program priorities, (2) developed long-term collaborative relationships among scientists from different offices, and (3) advanced our knowledge of deep-sea corals and sponges in the U.S. Pacific Islands to improve management of these important resources.

Major Research Projects

In response to the availability of particular field research resources, the Pacific Islands Deep-Sea Coral and Sponge Initiative research group conducted 8 specific projects. Biogeographic exploration work became a major priority of this initiative because of the presence of the *Okeanos Explorer*, and because so many areas of the Pacific had not been surveyed for deep-sea coral and sponge communities. Ecological field work remained focused primarily in the MHI and NWHI where the infrastructure and technical capacity existed to support this type of field work. Projects that received DSCRTP funding included:

1. Laboratory efforts to compile and synthesize existing data from deep-sea coral and sponge observations in the U.S. Pacific Islands and creation of a system to extract, compile, manage, document, and format existing and new biological observation data to national program standards for submittal into national deep-sea coral and sponge database.

2. Field and laboratory efforts to compile and create updated bathymetry and backscatter syntheses of the U.S. Pacific Islands from existing and new *EX* multibeam backscatter data, along with an interpretive geological substrate map for a limited number of the U.S. Pacific Islands.

3. Field work to collect multibeam data and laboratory analyses to interpret the bathymetry data for American Samoa, the Pacific Remote Islands, the Marianas Archipelago, and the Hawaiian Archipelago in depths shallower than 500 m.

4. Field efforts to survey and map areas of high abundance and diversity and determine the vertical distribution of deep-sea corals and sponges in the MHI, the Papahānaumokuākea Marine National Monument (enclosing the NWHI), the Pacific Remote Islands Marine National Monument, the Marianas Trench Marine National Monument, American Samoa, and the Pacific Remote Islands Areas (PRIAs).

5. Field and laboratory research to examine the population size-structure, ecology, growth rates, genetics, and distribution of black corals in Hawaii, including the establishment of monitoring sites to sample and study growth and post-harvest recovery rates of SCUBA-accessible black coral populations in the MHI.

6. Field surveys of SCUBA-accessible black coral populations in Hawaii and American Samoa to determine taxonomy and distribution of black corals in American Samoa.

7. Field and laboratory work to estimate community recruitment rates in new habitat (e.g., lava flow).

8. Field work to collect data on temperature, current direction, and flow rates from deployed instruments in known precious coral beds.

Each of the PIDCSI projects supported one or more of the DSCRTP objectives. The PIDCSI research aligned with the DSCSE Strategic Plan by addressing information needs that were identified in the implementation plan. The PIDCSI fieldwork addressed objectives that compile and synthesize existing data (Projects 1, 2, 3, and 4) and specifically locate, map, and characterize deep-sea coral and sponge ecosystems in the U.S. Pacific Islands region (Projects 3, 4, and 5). We mapped island slopes down to 500 m throughout the Pacific Islands region using multibeam instruments available on regional NOAA research vessels (Project 3). We conducted projects that examined the ecology of deep-sea corals and the effect of human activity on deep-sea coral and sponge ecosystems (Projects 4, 5, 6, and 7). The PIDCSI attempted to determine the physical and oceanographic conditions that contribute to the presence/absence of deep-sea corals and sponges (Projects 4, 5, 6, 7, and 8). We collected samples and data that should improve our understanding of deep-sea coral and sponge genetics, biogeography, and ecology (Projects 4, 5, and 6).

This work was made possible by the collaborative efforts of multiple people and organizations. An incomplete list is offered to show the project affiliations of some of the major contributors.

NOAA - Pacific Islands Fisheries Science Center (NOAA-PIFSC)

1) Michael Parke: Team Lead responsible for the overall coordination of the three-year field effort, including related analyses. Oversaw the planning and execution of the three-year fieldwork effort, including coordinating ship requests and field activities. Ensured fieldwork data, metadata, and deliverables were made accessible and appropriately archived within NOAA. Maintained communication channels with headquarters, team members, science center, Pacific Islands regional leadership, OER, and the Western Pacific Regional Fishery Management Council. Scientific co-lead on Projects 1, 3, and 4.

2) Frank Parrish: As chief scientist, ensured the research methods and results were scientifically sound. Identified NMFS deep-sea coral information needs and NMFS science assets. Presentedinterim and final results in reports, publications, and presentations as needed. Scientific lead for project 8 and collaborator on 4, 5, and 8.

3) Bruce Mundy: Lead for all fish identification and indefatiguable docent at the PIFSC remote video center.

4) John Rooney (deceased): Scientific co-lead on Project 3.

5) Annette DesRochers: Scientific co-lead on Project 3.

6) Frances Lichowski: Scientific co-lead on Project 3.

NOAA- OAR - Office of Ocean Exploration and Research (OER)

1) Kelley Elliot, Jeremy Potter, Brian Kennedy, and many others at OER: Served as EX mission leads and OER liaisons to the PIDSCI Team. Maintained connections between the PIDSCI-funded fieldwork and OER's exploration activities.

NOAA-NOS - Papahānaumokuākea Marine National Monument

1) Daniel Wagner (currently at Conservation International): Scientific lead on project 6. Scientific co-lead on Project 5. Collaborator on Projects 2 and 4.

2) Randall Kosaki: Built linkage with NOS science assets and expertise. Contributed to media and public outreach activities. Collaborator on Projects 4, 5, and 6.

University of Hawaii

1) Christopher Kelley: Scientific lead on Projects 4 and 8. Co-lead on Projects 1 and 2.

2) John Smith: Scientific lead on Project 2.

3) Rob Toonen: Scientific co-lead on Project 5.

4) Anthony Montgomery: Scientific lead on Project 5.

5) Virginia Moriwake: Co-lead on Project 1, collaborator on Project 4.

6) Meagan Putts: Scientific lead on Project 7, collaborator on Projects 1 and 4.

7) Sarah Bingo: Collaborator on Projects 1 and 4.

Hawaii Pacific University

1) Sam Kahng: Scientific co-lead on Project 7.

University of Louisiana at Lafayette

1) Scott France: Collaborator on Projects 1, 4, and 8.

University of Texas A&M and Florida State University

1) Brendan Roark, Collaborator on Project 8.

2) Amy Baco Taylor, Collaborator on Project 8.

University of Victoria

1) Henry Reiswig: Collaborator on Projects 1 and 4.

National Museum of Natural History-Smithsonian

1) Steven Cairns: Collaborator on Projects 1 and 4.

2) Steven Mah: Collaborator on Projects 1 and 4.

The PIDSCI advanced our knowledge of deep-sea coral and sponge ecology in the U.S. Pacific Islands and provided information that managers can utilize to protect and oversee these resources. This information includes high-resolution bathymetry and backscatter maps with coral and sponge species distributions, detailed taxonomic descriptions of various species, and characterizations of environmental factors that influence the formation of deep-sea coral and sponge communities.

Project 1. Laboratory efforts to compile and synthesize existing data from deep-sea coral and sponge observations in the U.S. Pacific Islands and creation of a system to extract, compile, manage, document, and format both archived and new biological observation data to national program standards for submittal into national deep-sea coral and sponge database.

Lead Investigator: Christopher Kelley—University of Hawaii (ckelley@hawaii.edu), Virginia Moriwake—University of Hawaii, Meagan Putts—University of Hawaii, Sarah Bingo—University of Hawaii, Michael Parke—NOAA PIFSC, (michael.parke@noaa.gov)

This project had multiple components: update of an existing HURL deep-sea coral database focused on Hawaii and the U.S. Pacific Islands for project planning and subsequent incorporation of coral observations into the National Deep-Sea Coral Program's database; creation of a robust imagery data extraction workflow and data system; creation of a deep-water animal identification guide from new and existing images to facilitate imagery annotation; annotation of images from new biological observations collected during the *Okeanos Explorer* expeditions from 2015 to 2017; collection and integration of track and CTD data for each ROV dive to enable visualization; and linkage of the submersible dive tracks and environmental data to biological observations.

Reviewing past research data was crucial in designing the three-year field research program. HURL is one of only two facilities of its kind committed to annotating its video archive from submersible dives conducted from 1981 to 2015. The 52,000+ HURL records examined/extracted included data from 1,014 dives. These annotated video data served to guide the planning for the overall exploratory field work by the *Okeanos Explorer*, and those data records that were subject to adequate quality assurance and control were deposited in the DSCP National Database to supplement material that had already previously been incorporated. Useful types of extracted data included annotated biological observations from archived HURL submersible and ROV dives, museum database records of specimens collected from deep water in the U.S. Pacific, and water quality data from CTD casts.

The database created from this effort facilitated the generation of information regarding the coral and sponge species present above 2,000 m in the region, as well as their locations, depths, preferred substrates, and associated communities of fish and invertebrates. The HURL team conducted an extensive review of existing deep-sea coral and sponge data obtained from Hawaii and the U.S. Pacific Islands in order to enhance a working database of known species and depth ranges. Initial steps in database updates, quality control, and format improvements used existing cnidarian records in the HURL archive, focusing first on gorgonians, antipatharians, and scleractinians before proceeding to the other cnidarian groups. Existing sponge records were corrected and formatted to meet the DSCRTP database standards, focusing first on glass sponges (hexactinellids) before proceeding to the other two sponge groups. These data were combined with HURL records previously provided to DSCRTP. The goal to supplement HURL observation data with video records from Monterey Bay Aquarium Research Institute (MBARI) submersible and ROV dives and museum collections of corals and sponges from the National Museum of Natural History (Smithsonian), the Bishop Museum, and the California Academy of Sciences were unrealized. Time constraints precluded the comprehensive integration of CTD data, submersible tracklines, and annotation of partner videos and data sets, but information from these collections still assisted project planners in determining a maximum depth limit for DSCP biological survey operations from 2015 to 2017. Extractions from these and other existing data sets also helped guide the PIDCSI research by identifying important research gaps.

While a great deal of useful species catalog data were recovered during this process, it became obvious that many of the older data sets had limited utility for further scientific analyses due to the lack of accurate geographic positioning and the lack of documented observational protocols. As such, more effort was directed to the creation of a deep-sea coral and sponge information system to extract, compile, manage, document, and format data from the 2015–2017 *Okeanos Explorer* videos (and other video systems) to national program standards for submittal into the national deep-sea coral and sponge database.Workflows were created to document non-substrate, water-column components important to these animals, such as temperature, salinity, dissolved oxygen, alkalinity, pCO2, and other factors at varying levels of resolution.

This development of a more efficient and accessible information system facilitated extraction, management, and documentation of new deep-sea coral and sponge data and took priority over further archive data recovery efforts. The HURL data team initiated data extraction from the ROV dives using the Video Annotation and Reference System (VARS) software created by the Monterrey Bay Aquarium Research Institute (MBARI). The protocol used VARS to create individual annotations of animals captured on the dive videos. In addition to animal identification, the annotation process extracted substrate/habitat data, flagged identification uncertainties, and included information on commensal organisms found on corals and sponges. Once each dive had been completely annotated, custom scripts were run in VARS to merge the tracking and CTD data to each of the annotations based on time codes. Records from the VARS database were formatted, subjected to QA/QC, and submitted to the DSCRTP national database. This new imagery data extraction, identification, and catalog system provided an efficient and effective workflow to not only enumerate and identify biological observations, but to link the observations to environmental conditions such as location, depth, temperature, salinity, dissolved oxygen, alkalinity, and pCO2. Over 92,500 records of biological observations from the CAPSTONE expeditions were produced using this methodology and submitted to the DSCRTP. These submissions included annotated identifications, as well as substrate observations, geographic positions, and water quality characteristics such as temperature, depth, salinity, and dissolved oxygen.

See Appendix 1. 20190410_Combined_Corals_Sponges_Associates.xlsx with 4 worksheets

In order to accurately and efficiently identify and annotate species from the *OE* videos and for future deep-sea expeditions, HURL developed a Benthic Deepwater Animal Identification Guide for OER, a collection of in-situ images created from video frame grabs taken from *Deep Discoverer* (*D2*) ROV video. The first pilot version of the guide served as a taxonomic reference of deep-water animals encountered during *D2* ROV dives around the Hawaiian Archipelago and Johnston Atoll in 2015. The second version included images of animals encountered during both 2015 and 2016 expeditions, the latter involving *D2* dives in Hawaiian Archipelago, Marianas Archipelago, and Wake Island. The third version of the guide included all the images of animals encountered during the 2017 expeditions involving *D2* dives in the South Pacific, Johnston Atoll, and the Musicians seamounts. The latest version contains all of the animal images from the entire 3-year CAPSTONE campaign in the Pacific. The guide is organized according to major taxa and identifications were made using local expertise supplemented with assistance from worldwide taxonomic experts who specialize in deep water animals. Experts provided their assistance through various avenues that included audio commentary and event log entries while the ROV dives were taking place, post dive email correspondence, and examination of images just prior to being posted on the OER website. This identification guide continues to incorporate new images from other research cruises, and updated species identifications from taxonomic experts, and currently contains ~4,500 images. Taxonomic revisions are particularly common for deep water animals, which are poorly known, and routine updates will continue as long as the identification guide is maintained.

https://oceanexplorer.noaa.gov/okeanos/animal_guide/animal_guide.html

The HURL team also created an onboard and post-cruise collection and processing protocol for both geological and biological specimens that was used during the 2015–2017 *D2* ROV dives. Throughout CAPSTONE, NOAA practiced a limited sampling protocol, only collecting a few voucher samples per dive. During 2015 and 2016, the only biological samples collected were those that were thought to be potential new species or demonstrated a substantial range extension. In 2017, the sampling protocol was widened to include collection of dominant-morphotype taxa that could not be identified by video. In addition, geological samples were collected on the majority of dives to aid in isotopically dating features and to help characterize the overall geology of the dive site.

CAPSTONE biological samples (390) included commensal organisms (112) found on corals (179) and sponges (99). Additional biological samples (142) were collected during the 2017 expedition to the Musician Seamounts. Most of the specimens were subsampled for DNA analysis as part of the Ocean Genomic Legacy (OGL) project, which provided the onboard processing kit used in the ship lab. These DNA aliquots were shipped to Northeastern University where the Ocean Genome Legacy Center is headquartered. Once they had been removed from the ship and transferred to the HURL lab at UH, selected coral and sponge specimens were split in order to provide subsamples to the Bishop Museum's Marine Invertebrate Collection. The main portion of each biological sample was shipped to the Smithsonian Institution Zoology Collection for incorporation into their catalogue. All rock samples (CAPSTONE–280, Musicians Expedition–31) were shipped to the Marine Geology Repository at Oregon State University. Details of these collections can be found in regional characterization reports submitted to the Deep-Sea Coral Research and Technology Program.

Project 2. Field and laboratory efforts to compile and create updated bathymetry and backscatter syntheses of the U.S. Pacific Islands from existing and new *EX* multibeam backscatter data, along with an interpretive geological substrate map for a limited number of the U.S. Pacific Islands.

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The Hawaiian Archipelago (main Hawaiian Islands and NWHI, the latter now enclosed within the Papahānaumokuākea Marine National Monument), along with the other monuments in the Pacific, has been the focus of many multibeam sonar mapping efforts. As a result, a significant data set of seafloor imagery for this region provided the basis for hypothesizing the relationship between substrate type/topography and deep-sea corals and sponges. As part of the PIDCSI, we collected, integrated, and made available all pertinent bathymetry, backscatter, and bathymetric derivative maps and data.

Beyond its basic operational need for use in manned submersible, ROV, and technical wet dive site planning, the acquisition of high-resolution seafloor mapping data is an essential precursor to making significant biological, geological, and oceanographic discoveries. However, these data can be both expensive and difficult to acquire in areas as remote as the Marine National Monuments of the Pacific. The lack of such data has restricted the pace of discoveries in the proposed regions of study.

The working biological hypotheses during the PIDSCI were that (1) high-density coral and sponge beds are more common on ridges oriented with accelerated current flow than on ridges with parallel orientation to it, and (2) high-density coral and sponges are more common on seamounts with ridge-like shapes and summits oriented perpendicular to the accelerated flow than cone-shaped seamounts. Identifying and mapping these ridges and seamounts of different shapes was critical to testing these hypotheses. High-resolution mapping data were used to determine the most beneifical sites for diving to investigate the deep-sea biological communities. The contiguous high-resolution multibeam bathymetry also allowed ecological modelers to project species distributions across unsampled locations. These high-quality mapping data proved invaluable for identifying the spatial extent of important benthic habitats, potential biological hotspots, and vulnerable species locations/distributions.

In a geological sense, quality multibeam data are vital for delineating and interpreting the morpho-structural origins of the deeper portions of seamounts and similar constructs including the base of the platforms and location of volcanic centers, rift zone ridges, and landslide features. Furthermore, these data allow scientists to model and understand the processes of mass wasting and sediment transport down canyons and debris chutes. More complete mapping at shallower depths permits better correlation of the drowned reef terraces surrounding many of the edifices and leads to a better understanding of their overall evolution. Fossil reefs host a record of sea-level variability and climate change and, along with analyses of recovered samples, provide a powerful tool for building a detailed paleoceanographic history with implications for the future.

These edifices, which are typically composed of volcanic material capped by carbonates (if they were once shallow enough), have yet another unique geologic feature: polymetallic crusts found at 800–2,500 m depths on their exposed rocky slopes that have precipitated from the overlying water at an average rate of 2.5 mm/Myr. The crusts found in the Central Pacific have the richest content of cobalt (Co) and other commercially valuable minerals in the world. A number of countries are now actively engaged in developing the technology to mine this resource, a process that will be extremely destructive to the associated biological communities. The total area of crust habitat inside the monuments is still unknown, but our surveys have indicated it is extensive. Similar geologic features exist outside but close to the monument boundaries and are likely to be targets of future exploratory and extraction efforts.

Researchers are still examining the CAPSTONE data to determine if there is a significant preference for or against sessile organisms attaching to these polymetallic crusts. The additional mapping conducted from 2015–2017 provides a more complete, high-resolution mosaic of the monuments' seafloor that serves not only as our basemap on which to display biological and geological results, but also serves as a roadmap, or catalyst, for further studies of the seamounts, ridges, banks, atolls, and island flanks in these protected areas in the future. This project provided a significant contribution toward understanding the ecosystem habitat and marine geology of the Pacific Monuments.

The *Okeanos Explorer* (*EX*) conducted multibeam mapping using an EM 302 multibeam sonar to map depths between 500 and 4,000 m. Survey planning was conducted with Hypack navigation software. Data acquisition, editing, and processing employed a variety of software systems including SIS, MB Systems, CARIS, and SABER. The multibeam data generated during the three-year mission contributed to the update and creation of new bathymetry and backscatter syntheses along with interpretive geological substrate maps for Pacific Islands areas under U.S. and other national jurisdictions. Data were merged with pre-existing multibeam data or existing syntheses and fused with the USGS GLORIA sidescan sonar mosaics (where available) to provide a full and robust picture of the subsurface. The new data provided researchers the ability to compare newly-mapped features with similar features and processes in the well-studied main Hawaiian Islands.

Using the *EX*, CAPSTONE conducted extensive mapping throughout the U.S. Pacific Islands and adjacent areas, totaling 597,230 km^2, with 323 total seamounts mapped (see Fig.1). Multibeam efforts mapped 10 atolls, 7 banks, 148 conical seamounts, 114 guyots, 24 islands, and 61 ridge seamounts. CAPSTONE mapped 363,526 km^2 within marine protected areas throughout the Pacific Islands, with 60.86% of these mapped protected areas falling within the US EEZ. Though CAPSTONE made a significant contribution to Pacific Ocean mapping efforts, more than 80% of the Pacific remains unmapped by modern techniques. More details of the CAPSTONE mapping effort can be found in the publication by Kennedy et al. (2019).

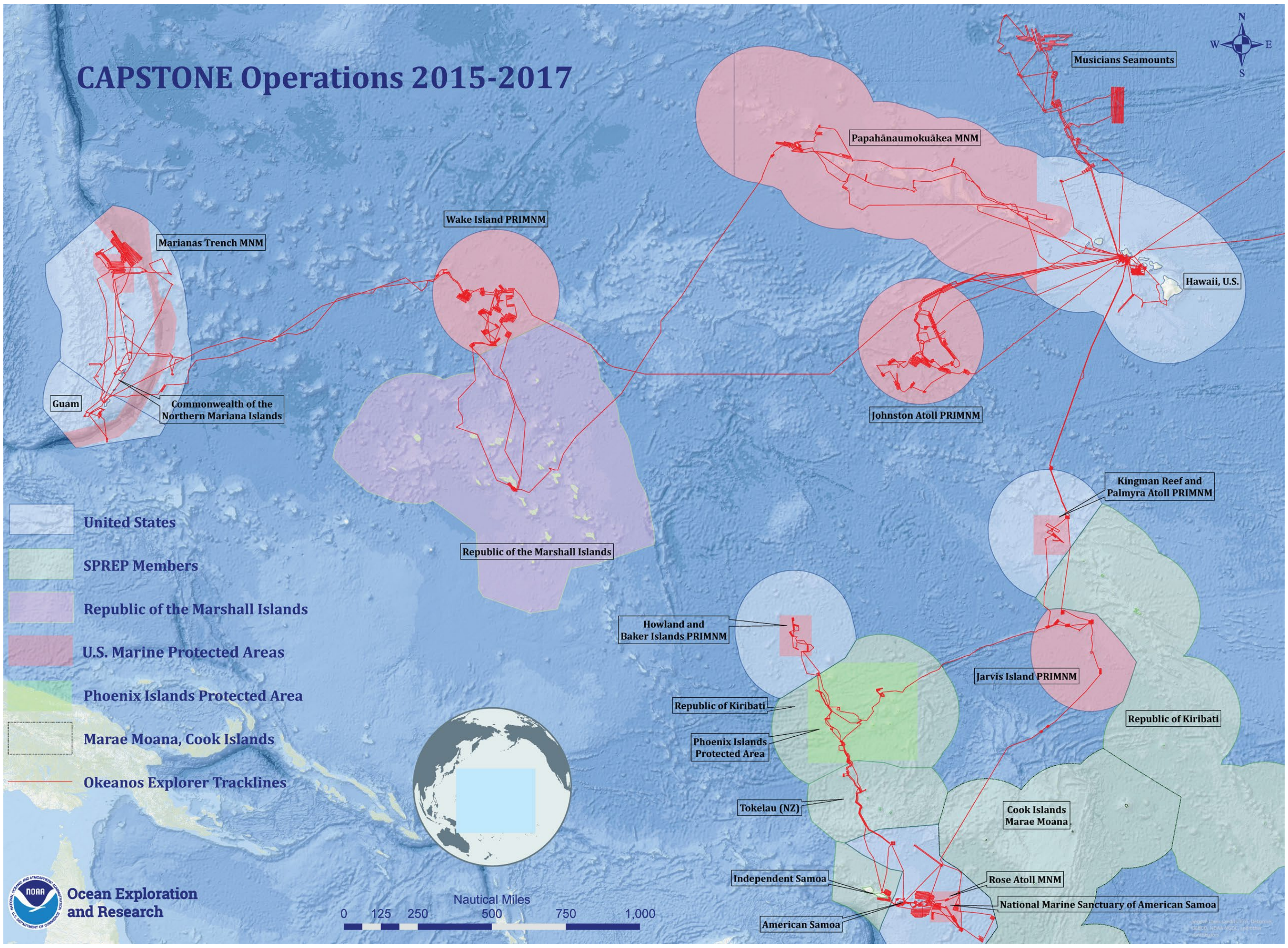

Figure 1. Geographic extent of CAPSTONE Operations 2015–2017.

These new bathymetry and backscatter data were combined with existing and new data from multiple sources to update regional bathymetric syntheses in the main Hawaiian Islands and the Papahanaumokuakea National Marine Monument. This facilitated research by many partners (http://www.soest.hawaii.edu/HMRG/multibeam/bathymetry.php) to develop a five-meter multibeam bathymetry and backscatter synthesis in bottomfish depths (to 500 m) for the main Hawaiian Islands for use in fisheries management, (http://www.soest.hawaii.edu/HMRG/multibeam/backscatter.php), to prepare a 60-m synthesis of all the multibeam bathymetry available in the Johnston Atoll area, and to officially name the 7 seamounts near Johnston Atoll that had never been mapped or named.

Multiple interpretive substrate maps of the geology and structure of the NWHI and Johnston Atoll are now available after rigorous interpretation and integration of multiple data sources. (https://schmidtocean.org/cruise/eyes-testing-uavs-mapping-johnston-atoll/#data)

Project 3: PIFSC multibeam surveys and analysis of bathymetry data from multiple instruments in Am. Samoa, PRIA, HI, and Marianas (focused on < 500 m)

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This research took advantage of the NOAA Ship *Hi'ialakai* multibeam refurbishments and enhanced sonar capabilities to fill gaps in coverage of deep-sea coral habitats (50–500 m depths) with ancillary missions using ship's personnel to collect data on a "not interfere" basis with the ship's primary missions. Surveying operations were conducted at night and during other periods when the ship's capabilities were under-utilized to provide cost-effective data collection and broader utilization of the ship's capabilities. Pacific Island deep-sea coral initiative funds were used to support updates of existing multibeam syntheses with more recent data and for preparation and delivery of those data to the *Hi'ialakai* which enabled surveying to fill gaps in coverage. Additional funding was used to process collected data, update existing multibeam bathymetry and backscatter syntheses and maps, and provide the data and associated metadata to the National Geophysical Data Center. Updated grids and maps showing the bathymetry and backscatter imagery around each island, along with associated metadata are available for viewing and download on the Pacific Islands Benthic Habitat Mapping Center website (http://www.soest.hawaii.edu/pibhmc).

The *Hi'ialakai* conducted surveys within deep-sea coral depths cruises in American Samoa, PRIA, and PMNM in FY15, and cruises to the MHI and PMNM in FY16. Mapping operations were conducted in select locations as determined by a bathymetry coverage gap analysis. Multibeam data were collected in 2015 using the NOAA Ship *Hi'ialakai* at Johnston, Howland, Baker, Swains, Palmyra, Tutuila, and Jarvis using both the EM3002D (not all islands) and the EM300. New multibeam data were collected by the NOAA Ship *Hi'ialakai* (HA) in the PMNM in 2016, and in the Mariana Islands in 2017. The project team staffed the HARAMP mission to provide direct support for the multibeam operations, and land-based support was also provided by the project team for all missions.

Due to a number of issues affecting multibeam data quality, new data products were only produced for a small number of surveyed sites, including Howland, Baker, and Guam. Quality data were acquired at other sites during the 2015–2017 RAMP cruises (e.g., at Aguijan, the last site surveyed in 2017); however, those areas had been previously surveyed, so the data were not used to update existing products.

Updated digital bathymetric models for Howland, Baker, and Guam are accessible on the Pacific Islands Benthic Habitat Mapping Center (PIBHMC) website (http://www.soest.hawaii.edu/pibhmc), and processed data have been archived at the NOAA National Centers for Environmental Information. All other data and derived surfaces have been preserved on the NOAA Pacific Islands Fisheries Science Center network for potential investigation in the future.

Figure 2 shows an example of the high-quality bathymetry data that were acquired when all sonar hardware, software, and personnel functioned properly, and followed acquisition protocols and best practices. Such data, when available, support and enable a great range of scientific research and monitoring. Unfortunately, each of the RAMP surveys experienced a number of significant problems that inhibited the consistent acquisition of high-quality data, such as lack of equipment testing at sea, ineffective calibration of seafloor depth, and imprecise differential GPS positioning. Together, these issues negatively affected much of the RAMP bathymetry data, resulting in limited mapping extents, failure to fill needed mapping gaps, poorly-constrained vertical controls, and inaccurate horizontal positioning. Despite efforts to identify and address these issues following the 2015 and 2016 RAMP surveys, several problems persisted through the 2017.

Future MBES surveys will require a better supported, dedicated effort that involves more effective integration between onshore and offshore activities from pre-cruise planning to surveying all the way through post-cruise processing.

ASRAMP

In 2015, NOAA Ship *Hiʻialakai* surveyed at Johnston, Howland, Baker, Swains, Palmyra, Tutuila, and Jarvis using both the EM3002D (not all islands) and the EM300. The sonar systems were sea-trialed prior to ASRAMP; therefore, the ASRAMP data suffered from fewer data quality issues than HARAMP and MARAMP. It is primarily because of data coverage (i.e., new data not covering significant gaps in existing data) that much of the ASRAMP data are not being used to update data products; only EM300 data from both Howland and Baker have been used to update existing bathymetric surfaces (e.g., Fig. 1).

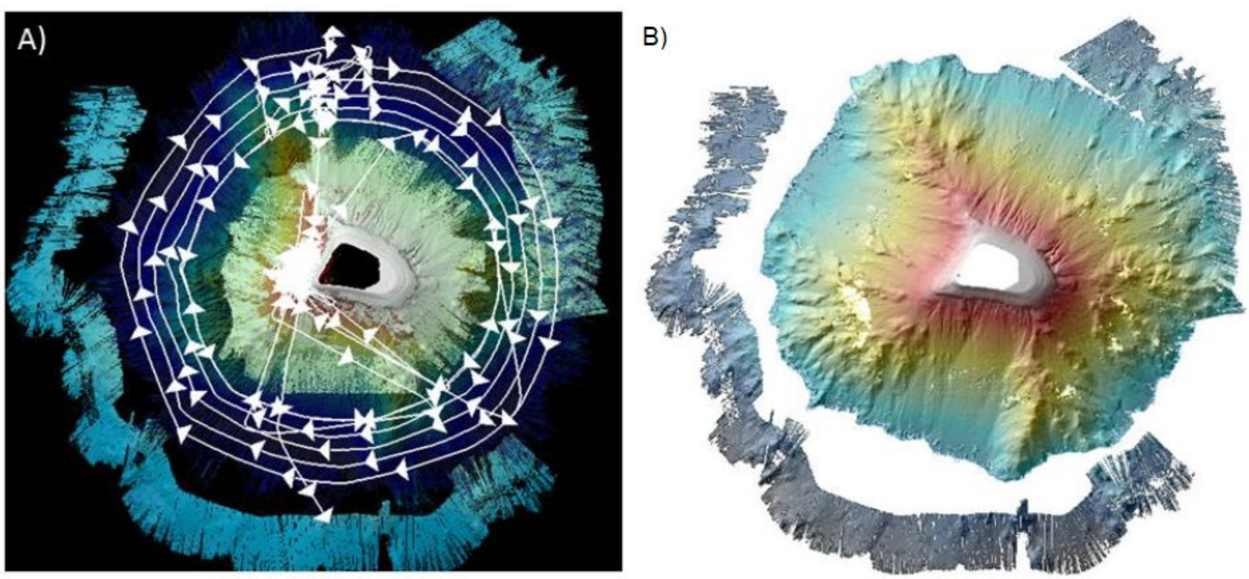

Figure 2. Inset (A) shows the location of new EM300 ASRAMP data at Baker (white lines) from 2015 with reference to existing PIBHMC 40 m² resolution surface. Inset (B) shows the new combined surface of the PIBHMC data and the processed ASRAMP 2015 data.

HARAMP

In 2016, NOAA Ship *Hiʻialakai* surveyed at French Frigate Shoals, Pearl and Hermes, Lisianski, and Kure islands using both the EM3002D (not all islands) and the EM300. Because of the issues highlighted above (mapping extent, vertical control, positioning), none of the bathymetry data acquired during HARAMP have been used to update existing products. It should also be noted that relatively little data were acquired at each island, particularly in the shallows. As such, even with high-quality data, it is unlikely that many of the existing data gaps would have been significantly filled.

MARAMP

In 2017, NOAA Ship *Hi'ialakai* surveyed at Guam and Aguijan using only the EM300. Following results from the patch-test conducted en route to CNMI and Guam, it became clear that the EM3002D was effectively inoperable (faulty starboard transducer head). EM300 data from Guam, despite having poor constraint on sound velocity that is mitigated by depth, cover significant areas of previously un-surveyed seafloor and therefore have been used to update existing data products. EM300 data acquired at Aguijan were high-quality with good vertical control due to correctly acquired sound velocity data; however, the data have not been used to update mapping products as they cover areas of seafloor that were previously surveyed.

A draft internal report, *Multibeam bathymetry data from 2015–2017 RAMP cruises (American Samoa RAMP or ASRAMP; HARAMP; MARAMP)*, has been prepared by the project team detailing the activities, findings, and challenges associated with the multibeam data collections during the Reef Assessment and Monitoring Program (RAMP) missions from 2015 to 2017. Plans were to merge all new data with previously acquired bathymetry data in each region to create seamless products and update the associated bathymetry data products to be published and archived online. The attempt to process new multibeam echo-sounder (MBES) bathymetry data (high-resolution EM3002D and medium-resolution EM300 sonars) acquired from the NOAA Ship *Hi'ialakai* within ~50–500 m depths during the 2015 ASRAMP (Pacific Remote Island Areas and American Samoa), 2016 HARAMP (Northwestern Hawaiian Islands [NWHI]), and 2017 MARAMP (Marianas) Reef Assessment and Monitoring Program (RAMP) cruises to support deep-sea coral research was ultimately unsatisfactory, with a few notable exceptions in the northern Marianas Archipelago.

Project 4. Field efforts to survey and map areas of high abundance and diversity and determine the vertical distribution of deep-sea corals and sponges in the MHI, the Papahanaumokuakea Marine National Monument, the Pacific Remote Islands Marine National Monument, the Marianas Trench Marine National Monument, American Samoa, and the Pacific Remote Islands Areas (PRIAs).

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Effective management of deep coral and sponge ecosystems in the Pacific Islands requires fundamental information regarding presence, location, diversity, and abundance of organisms. The Pacific Islands area is too large to systematically survey the distribution of corals and sponges throughout the region. Instead, the National Oceanic and Atmospheric Administration (NOAA) Office of Exploration and Research (OER) organized and implemented a three-year, Pacific-wide field campaign entitled CAPSTONE, Campaign to Address Pacific monument Science, Technology, and Ocean Needs, that attempted to optimize field operations by focusing on geological and oceanographic features, such as rift zone areas with topographically-induced upwelling, which previous surveys had identified as areas amenable to coral and sponge presence. NOAA, along with partners from academia, government, and the conservation community, completed a series of expeditions aboard NOAA Ship *Okeanos Explorer (EX)*, equipped with a dual-body remotely operated vehicle (ROV), the *Deep Discoverer (D2)*, capable of collecting biological and geological samples and diving to 6,000-meter depths, as well as four different types of mapping sonars.

The main objective of this fieldwork was to explore under-sampled regions of the U.S. Pacific Islands including the Hawaiian Archipelago, Johnston and Wake island areas, the Marianas Archipelago, the Pacific Remote Islands areas, and American Samoa, with a focus on U.S. marine protected areas including Papahānaumokuākea Marine National Monument, the Pacific Remote Islands Marine National Monument, the Marianas Trench Marine National Monument, National Marine Sanctuary of American Samoa, the Rose Atoll Marine National Monument. NOAA was able to partner with several Pacific Island countries and territories to expand the CAPSTONE effort internationally in support of the Pacific Oceanscape Framework and Big Ocean, the network of the world's large-scale marine managed areas. These areas include the Republic of Kiribati's Phoenix Islands Protected Area, Samoa, New Zealand's Territory of Tokelau, and the Cook Islands.

Under the auspices of CAPSTONE, and with support from the Office of Habitat Conservation Deep-Sea Coral Research and Technology Program and the Pacific Islands Fisheries Science Center, NOAA Ship *Okeanos Explorer* (*EX*) spent 431 days-at-sea completing 24 research cruises along with 187 ROV dives. The *EX* mapped over 635,000 km² of seafloor in the unknown and largely unexplored deepwater areas in the Pacific Islands in depths ranging from 250 m to 6,000 m and documented 323 seamounts. OER, PIDSCI, and partners conducted 187 *DD* ROV dives and amassed more than 890 hours of high-resolution benthic imaging video. By imaging more than 347,000 individual organisms, this expansive effort yielded new insights into differences in biodiversity across depths, regions, and features at multiple taxonomic scales. Due to survey protocols associated with *EX* missions and acknowledgement of the sensitive nature of protected areas, surveys focused on video observations with limited sampling. One major accomplishment of the PIDSCI included facilitating the development of sampling capacity and protocols for *D2* dives. Even these constrained sampling efforts collected 333 primary biological (along with many still-uncounted commensal organisms) and 278 geological samples. The *EX* telepresence capability actively engaged more than 260 participating scientists, students, and managers during ROV dives and streamed over16 million views of live video feeds of the expedition.

Multiple dive summaries, cruise/site characterization reports, regional summaries (Table 1), and publications that provide the details of this project have been produced, so only a brief summary of overall results and overviews by island region will be included in this document. For all deep-sea taxonomic groups large enough to be visualized with the ROV, we found that fewer than 20% of the species were able to be authoritatively identified. The most abundant and diverse taxa across the imagery data were from three phyla (Cnidaria, Porifera, and Echinodermata). Further examination of these phyla for taxonomic assemblage patterns by depth, geographic region, and geologic feature revealed that multiple genera displayed specific distribution and abundance by depth, region, and feature for each taxa. Both coral and sponge community density decreased significantly below 2,500 meters. Most corals and sponges were observed growing on consolidated bedrock with low amounts of sedimentation. Generally, isidids, chrysogorgiids, primnoids, and coralliids had a greater depth range and could be found deeper than 2,000 meters, with individual isidids, chrysogorgiids, and primnoids found even at the abyssal seafloor. Black corals, mostly schizopathids, were also documented below 2,800 meters. The lower limit of most plexaurids, paragorgiids, and acanthogorgiids tended to be shallower than 2,000 meters. Other coral genera exhibited broad abundance and distribution, which may focus future ecological research efforts. Sponges also demonstrated varied and broad presence and abundance. Novel taxa, records, and behaviors were observed, suggestive of many new types of species interactions, drivers of community composition, and overall diversity patterns. High-density (> 1000 colonies per lineal kilometer) coral communities were found deeper than 2,000 m but not below 2,800 meters. High-density communities were observed as deep as 2,800 meters, but no very high-density communities (> 10,000 colonies per lineal kilometer) were found below 2,400 m depth. Significant differences in dissolved oxygen minima, both values and depths, exist throughout the Pacific that are likely effecting basin-wide biogeographical patterns. *EX* exploratory dives do not result in evenly distributed effort with respect to either depth or region. This fact needs to be taken into account when analyzing dive data for either biogeographic or depth zonation patterns.

Table 1. A summary of the 8 characterization report regions and EX cruises. List of report number, region, cruise numbers into that region, and description (mapping or mapping and ROV) of activities performed in each region.

Report #	Region	Cruises	Description
1	Papahānaumokuākea Marine National Monument (PMNM)	EX1504L2	Mapping & ROV
		EX1603	Mapping & ROV
2	Main Hawaiian Islands & the Musician Seamounts	EX1504L3	Mapping & ROV
		EX1504L4 (dives 1-2)	Mapping & ROV
		EX1706 (dive 1)	Mapping & ROV
		EX1707	Mapping
		EX1708	Mapping & ROV
3	Johnston Unit of PRIMNM	EX1504L1	Mapping
		EX1504L4 (dives 3-13)	Mapping & ROV
		EX1706 (dives 2-15)	Mapping & ROV
4	Wake Unit of the Pacific Remote Islands Marine	EX1604	Mapping
	National Monument (PRIMNM)	EX1606	Mapping & ROV
	ISA Russia Lease Block	EX1607	Mapping
5	Mariana Archipelago	EX1605L1	Mapping & ROV
		EX1605L2	Mapping
		EX1605L3	Mapping & ROV
6	American Samoa & the Cook Islands	EX1701	Mapping
		EX1702	Mapping & ROV
		EX1703 (dive 1)	Mapping & ROV
		EX1704	Mapping
		EX1705 (dives 1-3)	Mapping & ROV
7	Tokelau Seamounts, Phoenix Islands Protected Area (PIPA),	EX1701	Mapping
	Howland & Baker Units of PRIMNM	EX1703 (dives 2-19)	Mapping & ROV
8	Jarvis, Palmyra, & Kingman Reef Units of PRIMNM	EX1701	Mapping
		EX1705 (dives 4-12)	Mapping & ROV

Main Hawaiian Islands and Musicians Seamounts Summary

(Excerpted from "A Report to the NOAA Deep-Sea Coral Research and Technology Program January 15, 2019. A Characterization of the Coral and Sponge Communities in the Main Hawaiian Islands, Geologist Seamounts, and the Musicians Seamounts from *Okeanos Explorer* Surveys Conducted Between August 28, 2015 and September 30, 2017.")

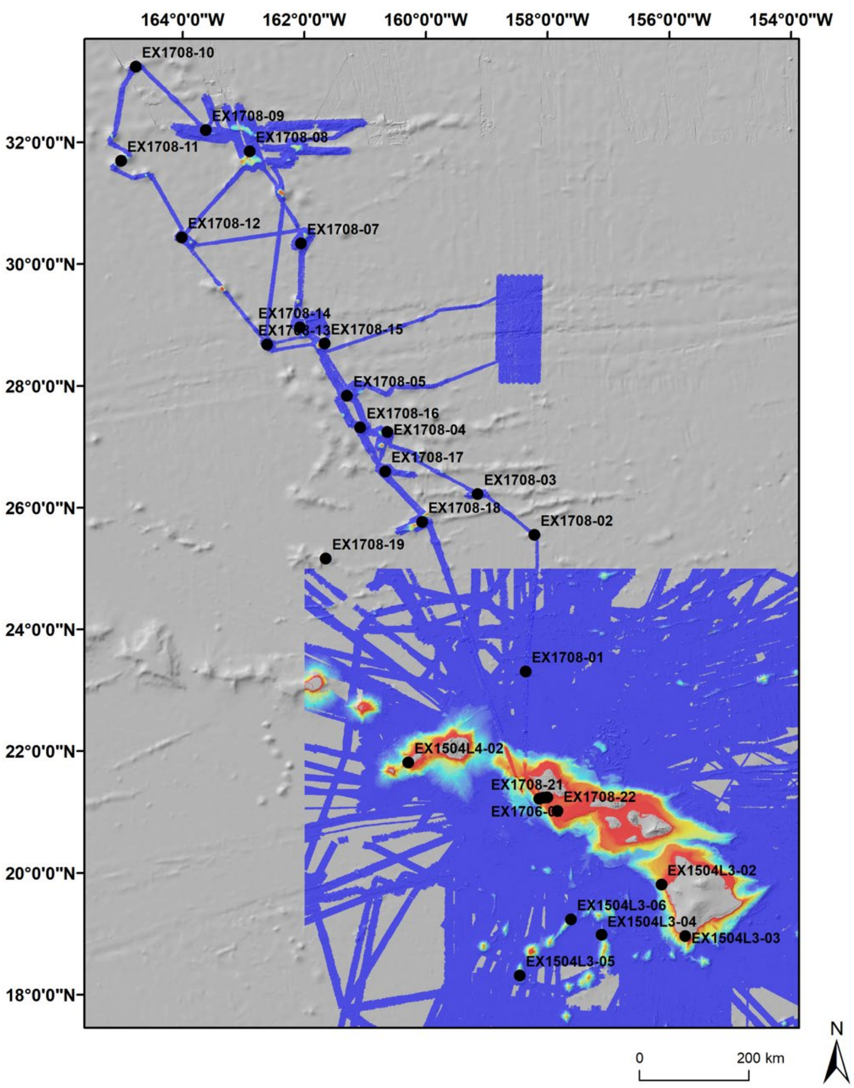

Figure 3. ***Deep Discoverer*** **ROV dives in the main Hawaiian Islands and Musicians Seamounts.**

High-density communities are defined as having at least 3,000 combined coral and sponge counts per kilometer; very high-density communities have over 10,000 counts per kilometer. Moderate-density communities are defined as those with 1,000–2,999 counts per kilometer, and low-density communities are those with less than 1,000 counts per kilometer. Using these definitions, fifteen of the 28 dive sites can be characterized as having high-density communities (Table 2). Corals were predominant at all but one of the high-density communities. Sponge densities greater than 1,000 individuals/km were only observed at two sites. Three of the high-density dives occurred at shallower precious coral depths within the EEZ of the main Hawaiian Islands (EX1504L4-02, EX1708-20, and EX1708-22), while the others occurred between 952 and 2,865 m. Figure 4 shows example images of several of these high-density communities.

Table 2. Summary of animal densities and environmental parameters at each dive site.

Dive #	Location	Depth (m)	Porifera/km	Cnidaria/km	Combined/km	Avg Depth (m)	Avg Temp (°C)	Avg O2 (mg/l)
EX1708-12	Mussorgsky Seamount	1953-2060	130	12357	12487	1993	1.9	2.65
EX1708-03	Beethoven Ridge	2300-2531	1857	10478	12335	2352	1.7	3.15
EX1708-17	Rapano Seamount	1896-2049	438	10795	11232	1933	2.0	2.67
EX1708-07	Debussy Seamount	2009-2053	957	9343	10300	2029	2.0	2.35
EX1708-13	Paganini Seamount	1756-1813	353	9353	9706	1772	2.2	2.47
EX1708-18	Schumann Seamount	2127-2316	312	7843	8155	2179	1.9	2.86
EX1504L4-02	Southwest coast of Niihau	312-573	169	6411	6580	387	8.3	3.06
EX1708-19	Mendelssohn Seamount	1649-1796	198	5809	6006	1710	2.2	2.48
EX1708-08	Wagner Seamount	2229-2430	85	5263	5348	2273	1.8	2.79
EX1504L3-06	Ellis Seamount	2063-2152	149	5112	5261	2103	2.0	2.95
EX1708-20	Middle Bank	296-479	177	4586	4762	344	11.4	6.02
EX1708-22	USS Baltimore	524-537	3715	1006	4721	**	6.4	2.09
EX1504L3-05	Swordfish Seamount	952-1076	106	4538	4644	983	4.2	1.58
EX1708-10	Shostakovich Seamount	2689-2865	717	2445	3163	2719	1.6	3.37
EX1708-04	Sibelius Seamount	2432-2646	98	3023	3121	2483	1.7	3.30
EX1708-01	Tropic of Cancer Seamount	1768-1855	188	2543	2731	1796	2.4	2.48
EX1504L3-02	Keahole off Kona Coast of the Big Island of Hawaii	376-393	18	2351	2368	385	8.2	2.60
EX1504L3-03	Kona Coast of the Big Island of Hawai'i	442-454	68	1717	1785	449	7.4	1.90
EX1504L3-07	S-19 Submarine	394-403	159	1425	1584	399	8.8	4.52
EX1504L4-01	South of Oahu	315-369	44	1439	1483	329	8.8	4.01
EX1708-02	Beach Ridge	3140-3282	36	907	943	3190	1.5	4.02
EX1708-21	Barbers Point - "Caiman" Anomaly	780-844	401	458	860	**	4.8	1.38
EX1708-15	Mozart Seamount	3571-3849	163	224	387	3696	1.5	4.19
EX1504L3-04	McCall Seamount	2634-2710	148	220	368	2670	1.6	3.69
EX1708-14	Liszt Seamount	2280-2562	44	236	280	2372	1.8	3.02
EX1708-05	Gounod Seamount	2636-2927	92	148	240	2715	1.6	3.49
EX1708-09	Verdi Seamount	3008-3092	23	142	165	3039	1.5	3.63
EX1706-01	Shakedown Operations Offshore of Oahu	465-467	0	40	40	466	6.8	2.27

**Depth removed to protect marine heritage resources.

Each seamount contained a unique species composition that can be seen in a breakdown of the top 10 most abundant taxa within each high-density dive. Even though there are obvious differences between the shallow-water and deep-water communities surveyed, it is difficult to determine whether the differences between communities at similar depths are a function of larval settlement or some other factors. One recurring observation was that each high-density community typically had 1–3 taxa accounting for the majority of the animal observations. In general, over 90% of the animal counts belonged to 10 or fewer different taxa (Fig. 5).

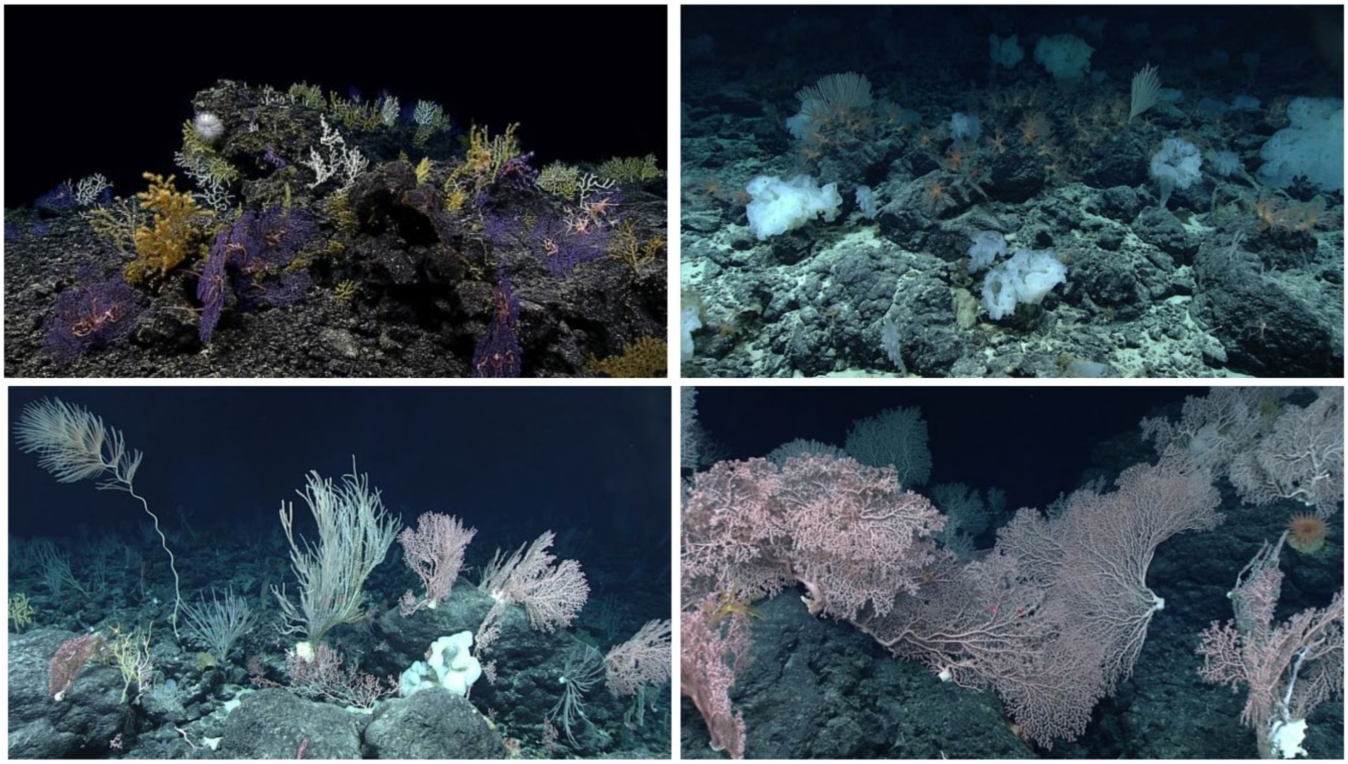

Figure 4. High-density communities discovered on Swordfish (upper left), Rapano (upper right) Debussy (lower left,) and Mendelssohn seamounts (lower right).

EX1504L3-07 was also conducted on the hull of the World War I submarine S-19 that was intentionally scuttled in 1938 and now serves as relatively new (~75 yrs old) hard substrate for deep corals to colonize (Fig. 6). The intact hull provides a unique glimpse of what could be considered a "pioneer" community of deep corals and sponges. Three-quarters of the counts at this moderate-density site were corals, most of which were primnoids. *Thouarella (Euthouarella) hilgendorfi* was the dominant taxon accounting for nearly half of the counts. Other primnoid taxa were also identified, such as *Narella* spp. (including *Narella muzikae*), *Callogorgia* spp. (including *C. gilberti* and *C. medialis)*, *Paracalyptrophora* sp., and several unidentified species. Sponges only accounted for 10% of the counts. The glass sponge family Euplectellidae was the second most numerous group of filter feeding animals on the wreck, all of which were in the genus *Regadrella*. Black corals, in particular *Stichopathes* sp. and *Bathypathes* sp., also contributed to about one tenth of the individual counts.

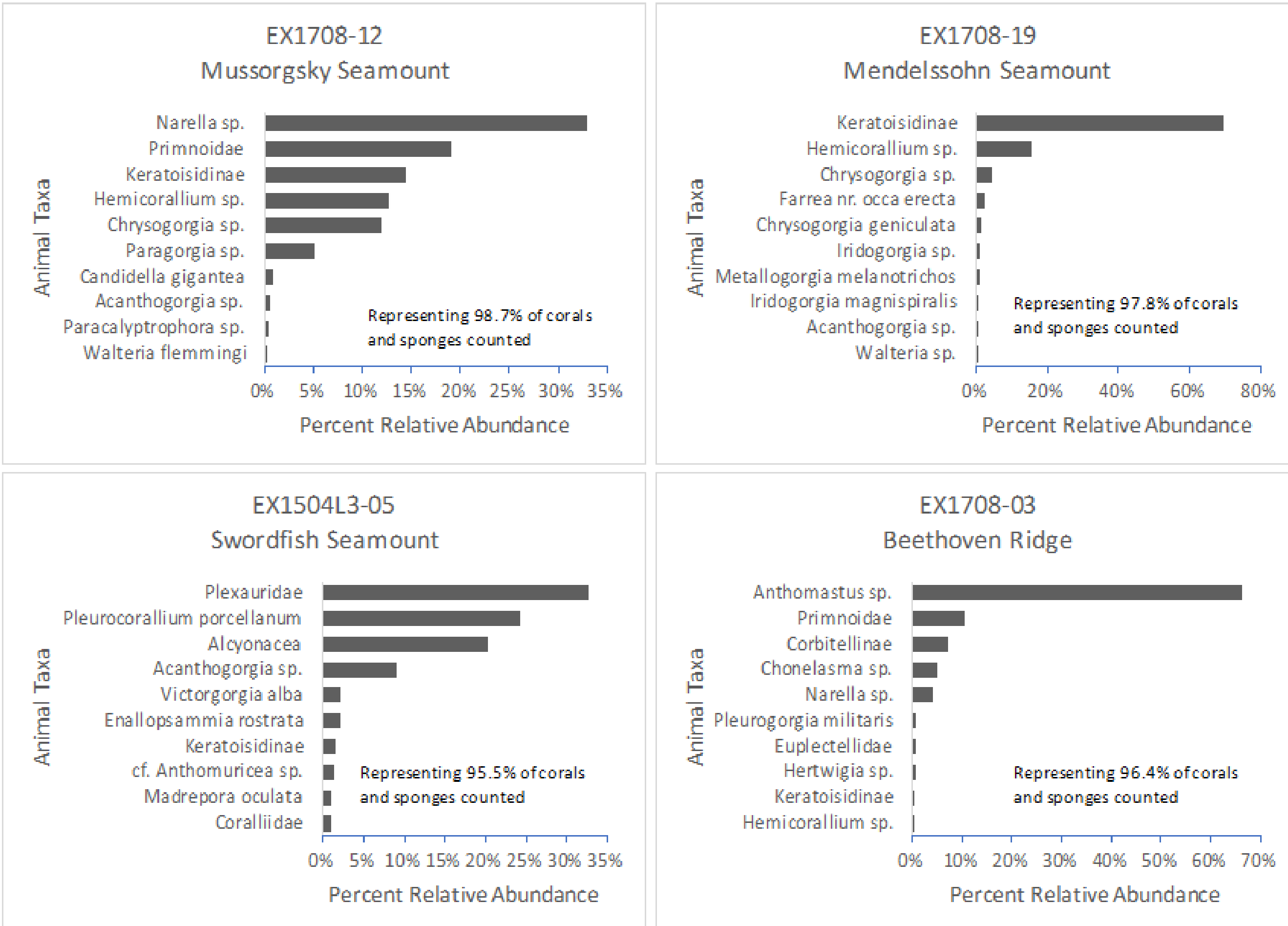

Figure 5. The percentage of total counts for the 10 most numerous taxa of corals and sponges observed at high-density sites found in this region.

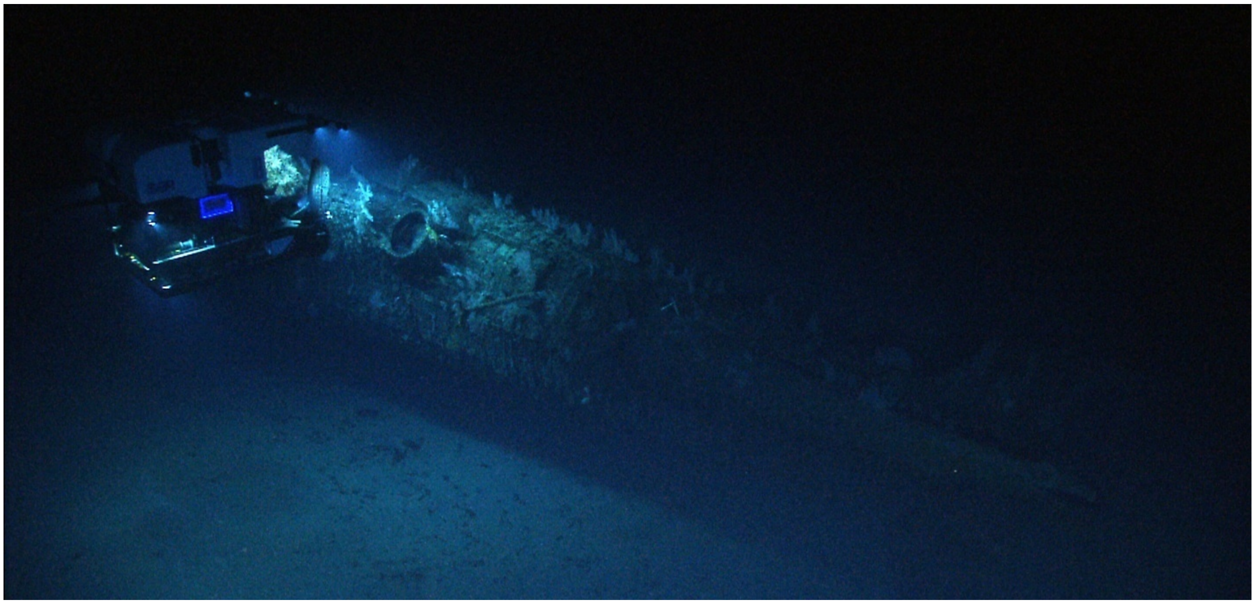

Figure 6. *D2* ROV surveying the S19 American submarine scuttled off Oahu in 1938.

Within the main Hawaiian Islands region, a total of 8 dives were conducted in shallow waters between 296 m and 573 m. Of these dives, three were conducted during EX1504L3, two were conducted during the EX1504L4 cruise, one dive from EX1706, and two from EX1708. The first two dives of EX1504L4 were in the MHI during the transit to PRIMNM. Both dives explored relatively shallow bottom habitats (312–573 m) and each had specific objectives. Dive 1 was used to recover two current meters off Barbers Point, Oahu, which had been deployed by Frank Parrish (NOAA-NMFS) to assess conditions affecting growth of precious gold corals. Several gold coral (Zoantharia) and black coral (Antipatharia) colonies were observed in the course of the dive. EX1504L4-02 explored a pinnacle in state waters southwest of Ni‘ihau, where the Hawaiian Islands Humpback Whale National Marine Sanctuary was considering expansion and was tasked with surveying deep fish and coral and sponge communities. This pinnacle was home to the highest diversities of corals and fish seen on leg 4, which may not be surprising given the relatively shallow depths surveyed. Of particular interest was the observation of a striking field of rock pens (Pennatulacea, likely *Calibelemnon symmetricum*) at ≈400 m depth, in very high densities that had not previously been reported; a specimen was collected for taxonomy. The survey at Middle Bank, EX1708-20, was on a pinnacle sticking up from the main terrace of the bank. A high-density community that included several large precious corals, such as the gold coral (*Kulamanamana haumeaae*) was discovered near the base and an extensive community of black corals near the summit.

Rift zone ridges were confirmed as sites of large-scale, high-density coral and sponge communities during the expedition. However, the surveys also revealed that the presence of a ridge does not guarantee the presence of a high-density community since other factors such as substrate consolidation and depth are clearly important. Ten seamount ridges were surveyed within this region, 3 of which were located in the Geologists Seamounts south of the main Hawaiian Islands (EX1504L3-04, -05, and -06) and 7 in the Musicians Seamounts (EX1708-02, EX1708-03, EX1708-07, EX1708-09, 1708-13, EX1708-15, and EX1708-18). Six of the 15 high-density communities were found on these ridge features.

The EX1504L3 ridge dives were conducted for the purpose of exploring the hypothesized relationship between ridge topography and large, high-density coral and sponge communities. While such a community was not found on the ridge crest of McCall Seamount, they were on the crests of both Swordfish and Ellis Seamounts (Fig. 11). Depth was again implicated as determinant for ridge community development since the dive on McCall Seamount was significantly deeper (2,700 m) than the dives on Swordfish (1,071 m) and Ellis (2,135 m) seamounts. Depth may also be a factor in determining the constituents of ridge communities as those on Swordfish and Ellis differed significantly. The Swordfish community was more varied with large numbers of plexaurids, coralliids, and acanthogorgiids, whereas isidids were dominant on Ellis. Substrate consolidation was clearly another factor; abundant solid rock was found on the crests of both Swordfish and Ellis seamounts, but not on McCall.

Manganese crusts were observed at 19 of the 28 sites surveyed in MHI and MUS. Manganese crust habitats supported a variety of different communities with both high and low densities of corals and sponges. Substrate rock type does not appear to influence the community density as both limestone and manganese crust bedrock environments exhibited low-density and high-density communities. However, substrate consolidation does appear to be an important factor for deep-sea corals and sponges since the majority of these animals recorded during the dives were observed attached to bedrock (Table 3). While less common, some taxa, particularly sponges, showed a preference for sediment, such as *Hyalonema* sp., *Semperella* sp., and *Sericolophus hawaiicus* in the order Amphidiscosida.

Table 3. Summary of contact or attachment substrate for different types of corals and sponges.

Phylum	Class	Order	Bedrock	Boulder	Cobble	Pebble	Sediment	Biological
Cnidaria	**Anthozoa**	Alcyonacea	73.9%	14.3%	11.7%	0.0%	0.0%	0.1%
		Antipatharia	89.0%	7.0%	3.8%	0.1%	0.0%	0.1%
		Pennatulacea	96.3%	0.1%	0.1%	0.0%	3.3%	0.1%
		Scleractinia	96.8%	1.0%	1.3%	0.0%	0.3%	0.6%
		Zoantharia	89.8%	0.5%	1.1%	0.5%	0.0%	8.0%
		Unidentified	56.5%	28.2%	15.3%	0.0%	0.0%	0.0%
	Hydrozoa	Anthoathecata	75.0%	25.0%	0.0%	0.0%	0.0%	0.0%
		Leptothecata	92.3%	5.5%	1.1%	0.0%	0.0%	1.1%
Cnidaria Total			**77.6%**	**12.2%**	**9.8%**	**0.0%**	**0.2%**	**0.2%**
Porifera	**Demospongiae**	Haplosclerida	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Poecilosclerida	57.1%	21.4%	21.4%	0.0%	0.0%	0.0%
		Tetractinellida	80.5%	17.0%	2.5%	0.0%	0.0%	0.0%
		Unidentified	76.1%	22.7%	1.1%	0.0%	0.0%	0.0%
	Hexactinellida	Amphidiscosida	27.5%	18.8%	10.2%	0.4%	43.1%	0.0%
		Hexasterophora incertae sedis	84.2%	5.3%	5.3%	0.0%	0.0%	5.3%
		Lyssacinosida	65.8%	24.2%	7.5%	0.0%	0.8%	1.6%
		Sceptrulophora	46.0%	37.8%	15.8%	0.2%	0.0%	0.2%
		Unidentified	39.0%	35.5%	22.0%	0.0%	0.0%	3.5%
	Unidentified	Unidentified	62.7%	13.6%	20.7%	0.6%	0.6%	1.8%
Porifera Total			**58.0%**	**26.7%**	**10.7%**	**0.1%**	**3.3%**	**1.2%**
Grand Total			**76.5%**	**13.0%**	**9.9%**	**0.0%**	**0.4%**	**0.2%**

Unlike the other seven regions surveyed during CAPSTONE, no monuments exist in this region, nor were any dives conducted on established sanctuaries. Nevertheless, this region is important to enhance our understanding of communities in close proximity to PMNM which may in turn bolster our knowledge of the geographic distribution of deep-sea corals and sponges. For that reason, conducting surveys of the biological resources in this region was valuable and the results are included here. As noted in other regional reports, a detailed analysis of the animal records is beyond the scope of this report. This section does provide some basic summary charts and tables of the corals, sponges, and the associated fauna found in this region. The organization of this information is similar for all eight regional reports and first provides pie charts showing the relative abundances of various groups of corals and sponges (Fig. 7). Detailed tables providing the counts for corals, sponges, and their associates for each species or lowest possible identification can be found in the regional reports. A total of 319 different taxa of corals, sponges, and their associated fauna were identified, including 165 cnidarians (152 corals and 13 cnidarian associates), 60 sponges, 2 annelids, 38 arthropods, 3 fish, 2 ctenophores, 41 echinoderms, 7 mollusks, and 1 unidentified animal.

Coral communities in this region were primarily composed of Alcyonacea, Antipatharia, Scleractinia, and Pennatulacea in order from greatest to least abundant. Together the four orders of Anthozoa accounted for 99% of the corals observed. Alcyonaceans were the most abundant, representing over 80% of the counts. Within the Alcyonaceans, 14 different families (although one was c.f. Anthothelidae) were identified while 2% of the corals counted could not be identified to family. Interestingly, the most abundant family, Chrysogorgiidae, only contributed 23% to all alcyonacean counts, followed closely by Coralliidae, Isididae, and Primnoidae at 21%, 19%, and 17%, respectively. The richness in taxa and evenness among families suggest that Musicians Seamounts and main Hawaiian Islands have a high diversity of corals. Tetractinellids, specifically ribbon sponges in the genus Poecillastra, were the most abundant demosponges, and lyssacinosidans were the most abundant glass sponges, particularly vase sponges in the family Euplectellidae. Sceptrulophorans in the families Euretidae and Farreidae were also abundant.

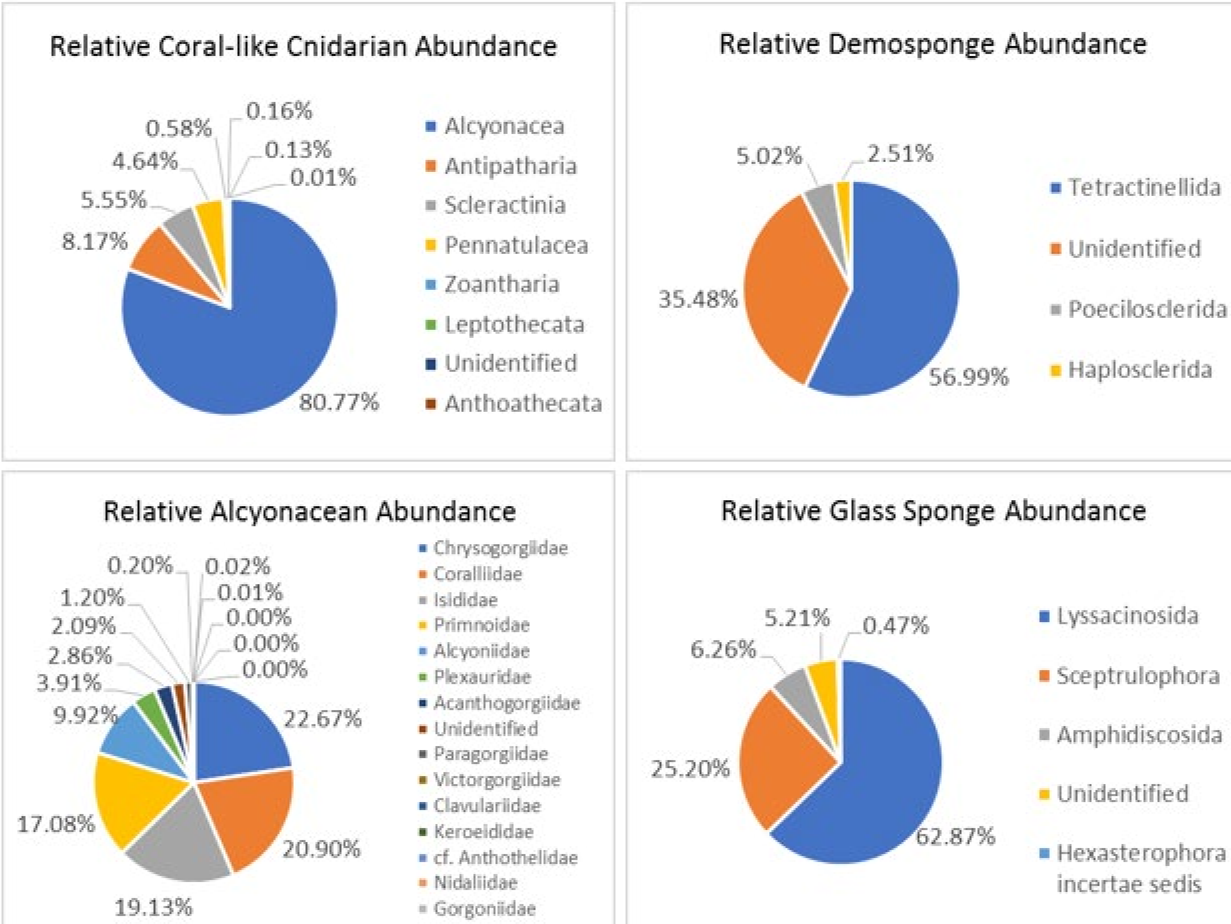

Figure 7. Relative abundance of observed corals and structure-forming hydrozoans (upper left), alcyonaceans (lower left), demosponges (upper right), and glass sponges (Hexactinellida, lower right).

The most common phylum of animals found associated with corals and sponges in this region were echinoderms. More than 80% of the echinoderm associates counted were ophiuroids, most of which were found on gorgonian corals. Notable associations include euralids with coralliids, paragorgiids, and plexaurids, as well as ophiacanthids with corallids, isidids, and primnoids. While sponges were less abundant than corals, roughly the same proportion (i.e., 5–6%) of the associate to host (sponge or coral) counts, were echinoderms. Ophiuroids and crinoids were equally represented and accounted for 99% of echinoderms associating with sponges, nearly three-quarters of which were euplectellids. Arthopods and cnidarians were also common associates of corals and sponges, particularly poecilasmatid barnacles on isidid colonies, squat lobsters in the genus *Uroptychus* on chrysogorgiid corals, decapod shrimp (including *Lebbeus* sp.) on euplectellids sponges, anemones (including *Amphianthus* sp.) on isidids, primnoids, chrysogorgiids and demosponges, and parazoanthids on isidids.

While the MHI part of this region has been relatively well studied, new species were still discovered during CAPSTONE. Almost all new descriptions of species require careful examination of collected specimens. At this point, it is difficult to determine the number of new species that were discovered during the dives since many have not been carefully examined by taxonomic specialists. Dr. Stephen Cairns has described 4 new species of primnoids from collections in this region: *Calyptrophora carinata, Narella aurantiaca*, *N. virgosa*, and *Macroprimnoa ornata*, and identified a new species of cup coral in the genus *Coenocyathus*. Other potential new species include a specimen of *Bathypathes* from EX1708-02 and a tube anemone in the genus *Botrucnidifer* collected during EX1708-03. Figure 8 shows examples of some of these collected specimens.

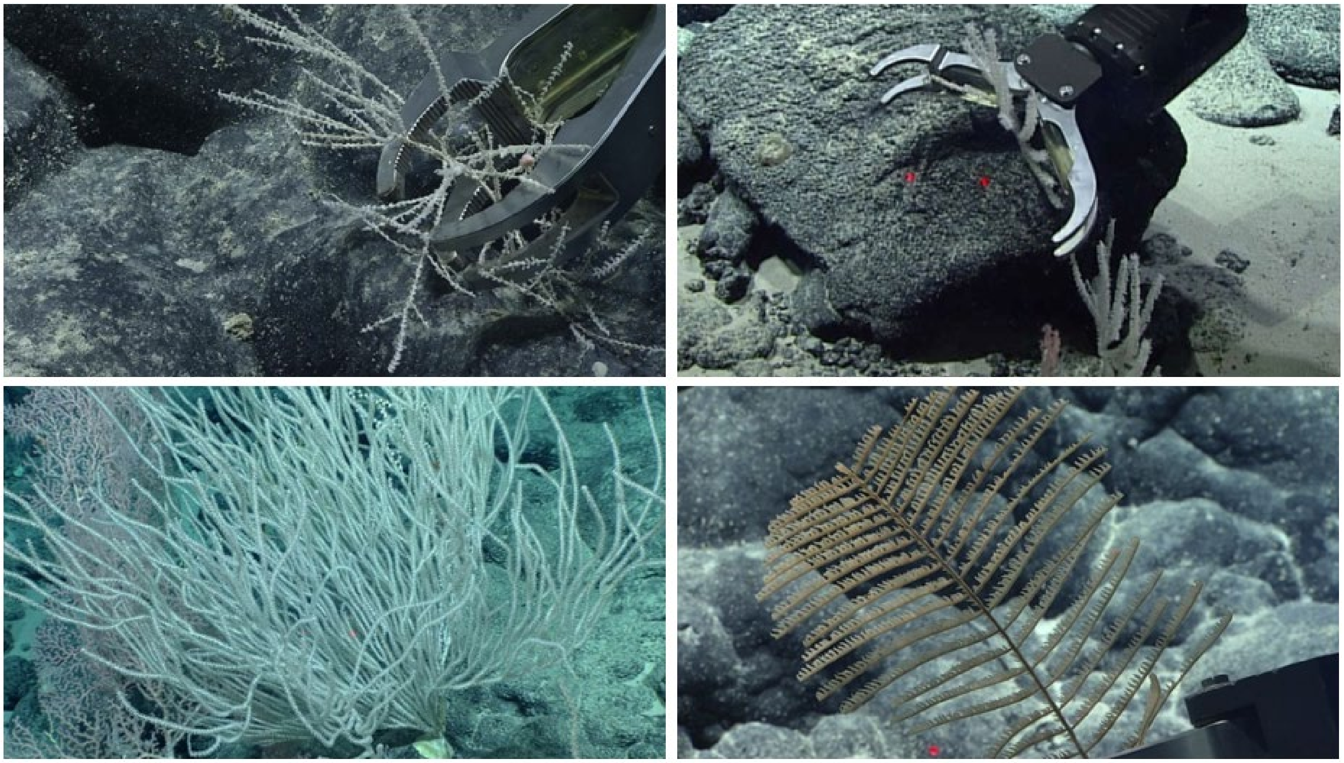

Figure 8. New species of primnoids, *Calyptrophora carinata* (upper left), *N. aurantiaca* (upper right), and *Narella virgosa* (lower left), and a potential new species of black coral in the genus *Bathypathe*s (lower right).

Northwestern Hawaiian Islands (Papahānaumokuākea MNM) Summary

(Excerpted from "A Report to the NOAA Deep-Sea Coral Research and Technology Program March 21, 2019. Characterization of the Coral and Sponge Communities in the Papahānaumokuākea Marine National Monument from *Okeanos Explorer* Surveys Between July 31, 2015 and March 18, 2016.")

Analyses of data extracted from video imagery resulted in baseline characterizations of large-scale, high-density deep-sea coral and sponge communities. For this and other summary reports, high-density communities are defined as having at least 3,000 combined coral and sponge counts per kilometer with very high-density communities having over 10,000 counts per kilometer. Moderate-density communities are defined as those with 1,000–2,999 combined counts per kilometer and low-density communities are those with less than 1,000 combined per kilometer. High-density communities of deep-sea corals and sponges were recorded on 12 dive sites, and moderate densities were observed at 8 other sites. Three of the high-density sites were previously known and the dives at these locations were designed to provide additional information on their extents. Figure 9 shows 4 examples of the high-density communities previously undiscovered in PMNM. All of the high-density communities were observed above 2,500 m depth (Table 4). This is also true of the moderate-density communities with one exception (dive EX1603-08) where an unusually dense community was found at depths approaching 4,000 m, unlike other dives conducted elsewhere at these depths.

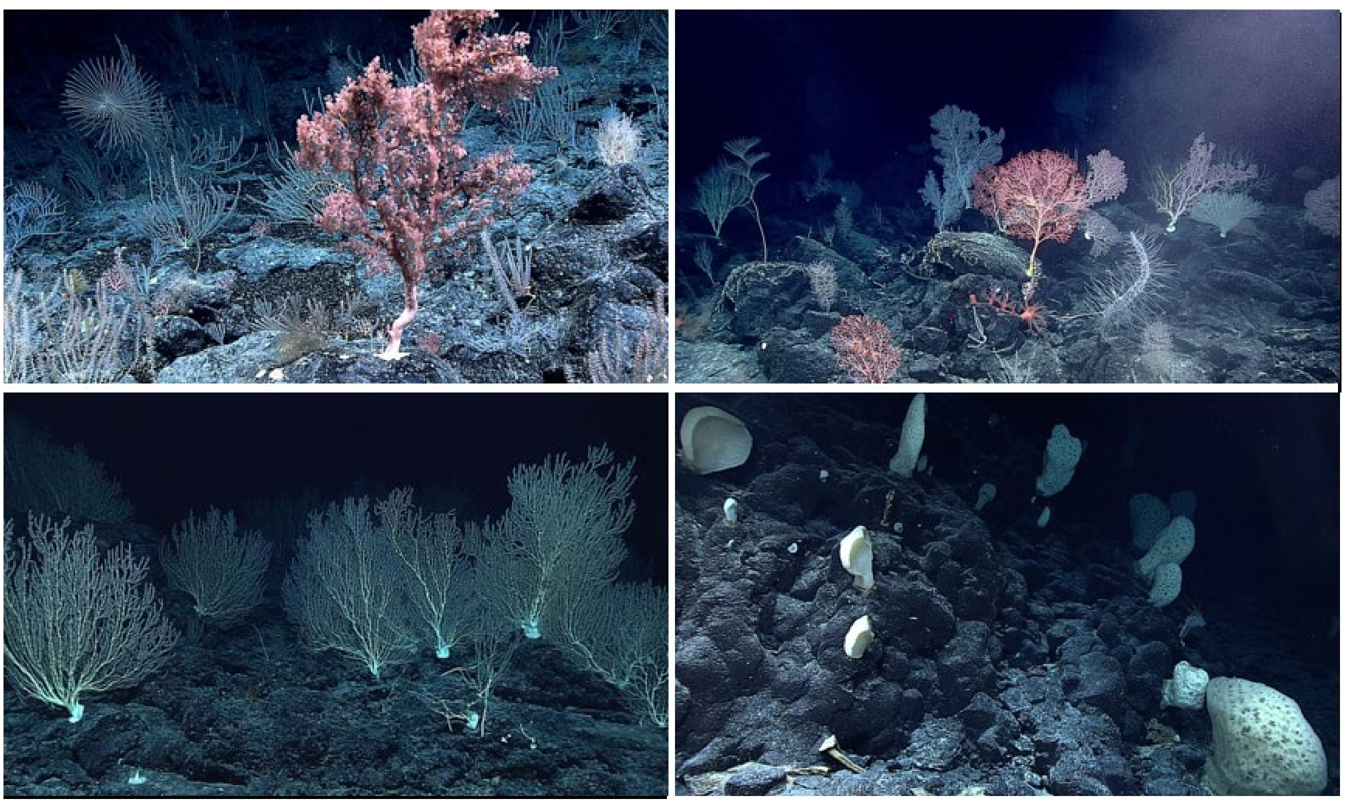

Figure 9. High-density communities of deep-sea corals and sponges encountered at various dive sites in the PMNM region.

Seven cnidarian families represented 90% of all observed corals in these communities that included the gorgonian octocoral families: Isididae, Chrysogorgiidae, Primnoidae, Coralliidae, and

Acanthogorgiidae; the hydrocoral family Stylasteridae; and the black hexacoral family Schizopathidae. In general, each community was unique in terms of its dominant constituents (Fig. 10) although there was clearly crossover between communities with some of the same species and/or taxa. Similar to high-density communities found elsewhere, the 10 most abundant taxa at each site accounted for over 80% of the total coral and sponges counted. With a few exceptions, the single most abundant taxon differed at each site and included different species of isidids, many of which could only be confidently identified as Keratoisidinae, a chrysogorgiid, a stylasterid hydrozoan, an acanthogorgiid, a primnoid, a coralliid, and a hexactinellid sponge in the family Pheronematidae. The community composition was unique at each site. Antipatharia were also in abundance at several of the sites, as well as paragorgiids and euplectellid sponges in the genus *Walteria*. Since most of the dives were conducted in roughly the same depth range, other factors are likely responsible for the observed differences in community composition.

Table 4. Animal densities by dive ordered from highest to lowest coral and sponge counts per surveyed distance.

Dive #	Location	Depth (m)	Porifera/km	Cnidaria/km	Combined/km	Avg Depth (m)	Avg Temp (°C)	Avg O2 (mg/l)
EX1504L2-07	Pioneer Bank Ridge	1997-2117	190	11450	11640	2070	1.9	2.98
EX1504L2-11	Bank 9 North	2092-2156	4070	6110	10180	2125	1.8	3.07
EX1504L2-10	Salmon Bank Southeast Ridge	1846-2050	520	6470	6990	1924	2.0	2.63
EX1504L2-06	West Northampton Seamount Ridge	1782-1996	1240	5630	6860	1838	2.0	2.77
EX1504L2-14	North Pioneer Ridge	1518-1644	610	4840	5450	1562	2.3	2.25
EX1603-03	South of Pioneer Bank	2307-2359	110	5290	5410	2327	1.7	3.54
EX1504L2-17	East North Gardner	1979-2084	550	3900	4450	2022	1.9	2.98
EX1504L2-02	North French Frigate Shoals (Kanehunamoku Seamount)	2223-2482	220	3930	4150	2336	1.8	3.13
EX1504L2-15	North Maro Ridge	1553-1751	110	3870	3980	1636	2.3	2.42
EX1603-07	Castellano Seamount	1824-2019	460	3370	3830	1939	2.0	2.83
EX1504L2-13	East Pearl & Hermes	2111-2304	60	3290	3360	2197	1.8	2.92
EX1504L2-18	West Nihoa	1482-1597	1150	1850	3000	1536	2.6	2.35
EX1603-08	Unnamed Seamount	3915-3990	440	2370	2820	3947	1.4	4.62
EX1504L2-03	St. Rogatien Rift, north of St. Rogatien Bank	1949-2154	240	2270	2520	2010	1.9	2.92
EX1504L2-09	East Salmon Bank	2101-2281	540	1640	2180	2214	1.8	3.04
EX1603-05	Unnamed Seamount East of Bank 9	1585-1757	280	1890	2160	1664	2.4	2.44
EX1504L2-16	Gardner Terrace	1407-1561	1620	510	2130	1447	2.7	2.12
EX1504L2-01	East Necker Seamount (Keoea Seamount)	1835-2219	480	1380	1860	1918	2.1	2.77
EX1603-04	North Side of Pioneer Bank	1154-1515	1250	540	1790	1222	3.1	1.41
EX1603-06	Unnamed Seamount West of Salmon Bank	646-1292	100	910	1020	956	4.0	1.41
EX1603-02	North Side of French Frigate Shoals	1087-1406	100	850	950	1185	3.3	1.80
EX1504L2-08	Bank 9 South	1081-1379	170	610	770	1276	2.9	1.35
EX1504L2-12	Southeast Pearl & Hermes Ridge	2764-2797	190	430	620	2777	1.5	3.72
EX1504L2-04	Maro Crater	2654-3032	60	100	160	2825	1.6	3.61
EX1504L2-05	Southeast Maro Ridge	4679-4824	130	0	130	4752	1.5	4.72
EX1603-01	Northeast Side of Necker Island	4222-4283	10	20	40	4250	1.5	4.56

The working hypothesis for all dive surveys was that that ridges perpendicular to the prevailing direction of bottom current flow would be one type of topography where large-scale, high-density coral and sponge communities are found. Current flow was almost uniformly perpendicular to ridges where high-density communities were found as were many of the larger coral colonies, providing support for this hypothesis. While additional ridge surveys are clearly needed, the important observations and data acquired during the expedition surveys on these features indicate that at least some rift zone ridges are sites of large-scale, high-density coral and sponge communities. However, the surveys also revealed that the presence of a ridge does not guarantee the presence of a high-density community since other factors such as substrate consolidation and depth are clearly important.

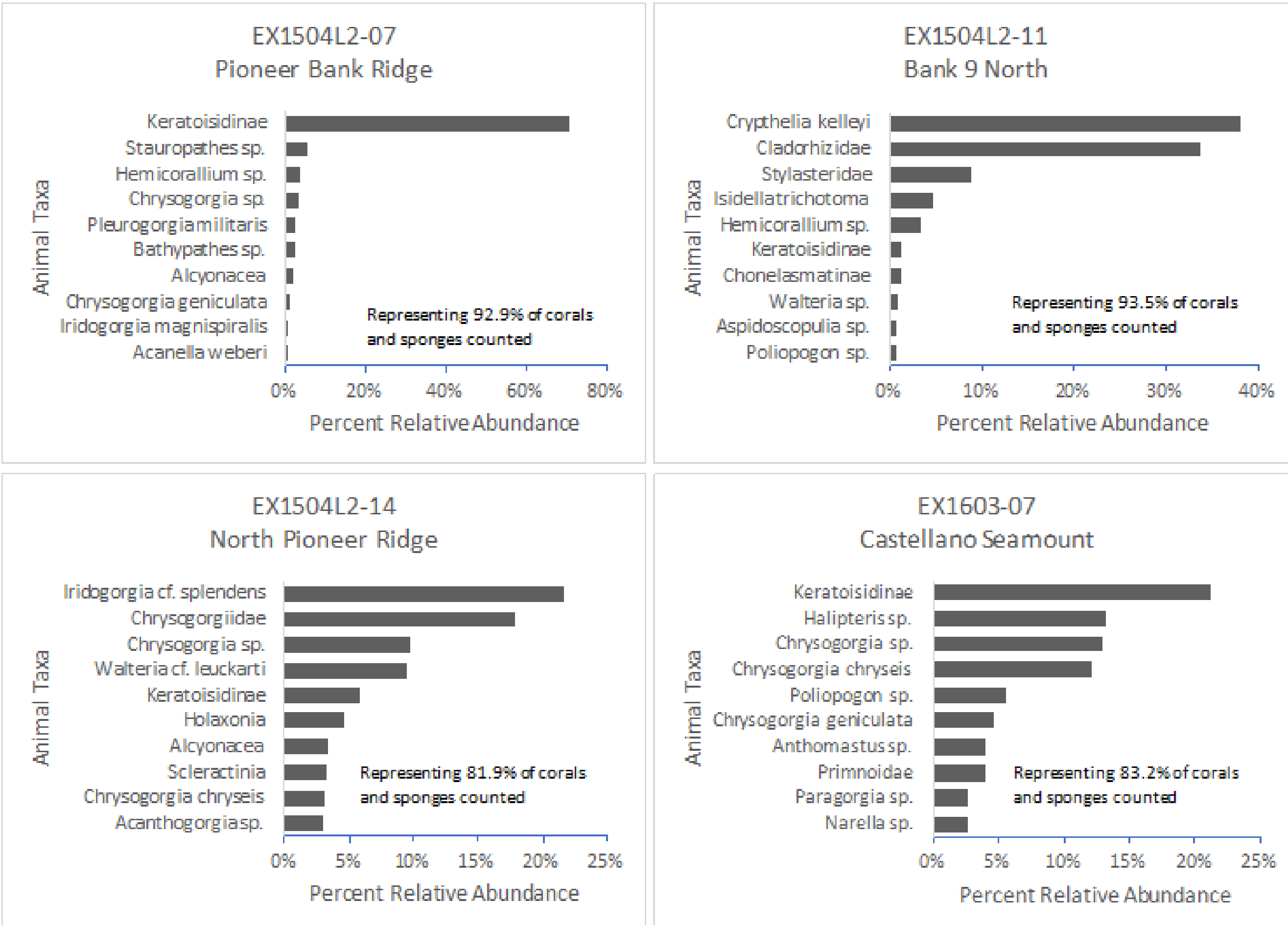

Figure 10. The percentage of total counts for the 10 most numerous taxa of corals and sponges observed at 4 high-density sites found in this region.

Within a single dive, the community density varied along the same ridge feature, in some cases in correlation with the degree of substrate consolidation. The question of whether more of these communities may be found on younger ridges (<30 million years) compared to older ridges (>60 million years) remains to be answered, the latter being where pillow lava formations are much more broken up due to their age. Most of the dives in PMNM were not within the designated prime crust zone (PCZ); however, Mn crust substrate was observed throughout the monument. James Hein (pers. comm.) confirmed that the existing boundaries in the northeastern part of the PCZ were designated with logistical considerations in mind, such as weather and sea conditions, rather than on the presence or absence of Mn crusts. Therefore, ROV surveys throughout PMNM still provide valuable information on Mn crust communities in the central Pacific that could be impacted by deep-sea mining activities in the future. Twenty-three of the 26 *D2* ROV dives found manganese-coated substrates. Twenty-one of those 23 dives took place within the optimal crust mining depth of 1,000–2,500 m. The crusts encountered during these dives had varying thicknesses, presumably related to seamount age, whether the dive site was at or near a flank failure, degree of sedimentation as well as other factors. The video and samples collected during these dives, along with the annotation records generated from the videos, represent a major contribution toward understanding these poorly characterized communities. Even before the video had been completely annotated, it was clear that this objective was achieved. All the dive surveys with dense benthic communities had large sections of unbroken Mn-encrusted basalt that provided firm attachment substrate for corals and sponges.

Substrate consolidation does appear to be an important factor for deep-sea corals and sponges since the majority of these animals recorded during the dives were observed attached to bedrock (Table 5). Dive sites with lower-density communities tended to have a greater proportion of sediment and unconsolidated substrate than locations where high-density communities occurred. These observations should prove useful for evaluating the potential impacts of future Mn crust mining since that industry will likely be targeting areas of seamounts where the substrate is highly consolidated and with low sediment cover.

All 26 dives were conducted within the boundaries of PMNM. A detailed analysis of the animals recorded within this monument unit is beyond the scope of this report. This section does provide some basic summary charts and tables of the corals, sponges, and their associated fauna found in this region. Pie charts show the relative abundances of various groups of corals and sponges (Fig. 11). Detailed tables providing the counts for corals, sponges, and their associates for each species or lowest possible identification are available in the regional report.

Table 5. Summary of contact or attachment substrate for different types of corals and sponges.

Phylum	Class	Order	Bedrock	Boulder	Cobble	Pebble	Sediment	Biological
Cnidaria	**Anthozoa**	Alcyonacea	84.0%	5.5%	10.4%	0.0%	0.0%	0.1%
		Antipatharia	89.1%	4.4%	4.5%	0.0%	0.0%	2.1%
		Pennatulacea	79.1%	0.5%	5.7%	3.2%	10.4%	1.2%
		Scleractinia	88.8%	5.0%	5.3%	0.6%	0.3%	0.0%
		Unidentified	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Hydrozoa	Anthoathecata	78.0%	18.2%	3.8%	0.0%	0.0%	0.0%
Cnidaria Total			**83.8%**	**6.2%**	**9.5%**	**0.1%**	**0.1%**	**0.2%**
Porifera	**Demospongiae**	Poecilosclerida	95.4%	3.6%	1.0%	0.0%	0.0%	0.0%
		Tetractinellida	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Unidentified	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Hexactinellida	Amphidiscosida	86.7%	5.8%	7.0%	0.0%	0.1%	0.4%
		Hexasterophora incertae sedis	48.1%	8.5%	43.4%	0.0%	0.0%	0.0%
		Lyssacinosida	82.6%	6.2%	10.9%	0.2%	0.1%	0.1%
		Sceptrulophora	84.7%	5.3%	10.0%	0.0%	0.0%	0.0%
		Unidentified	45.5%	18.8%	35.2%	0.6%	0.0%	0.0%
	Unidentified	Unidentified	78.3%	6.8%	13.9%	0.0%	0.3%	0.6%
Porifera Total			**86.6%**	**5.5%**	**7.6%**	**0.1%**	**0.1%**	**0.2%**
Grand Total			**84.3%**	**6.1%**	**9.2%**	**0.1%**	**0.1%**	**0.2%**

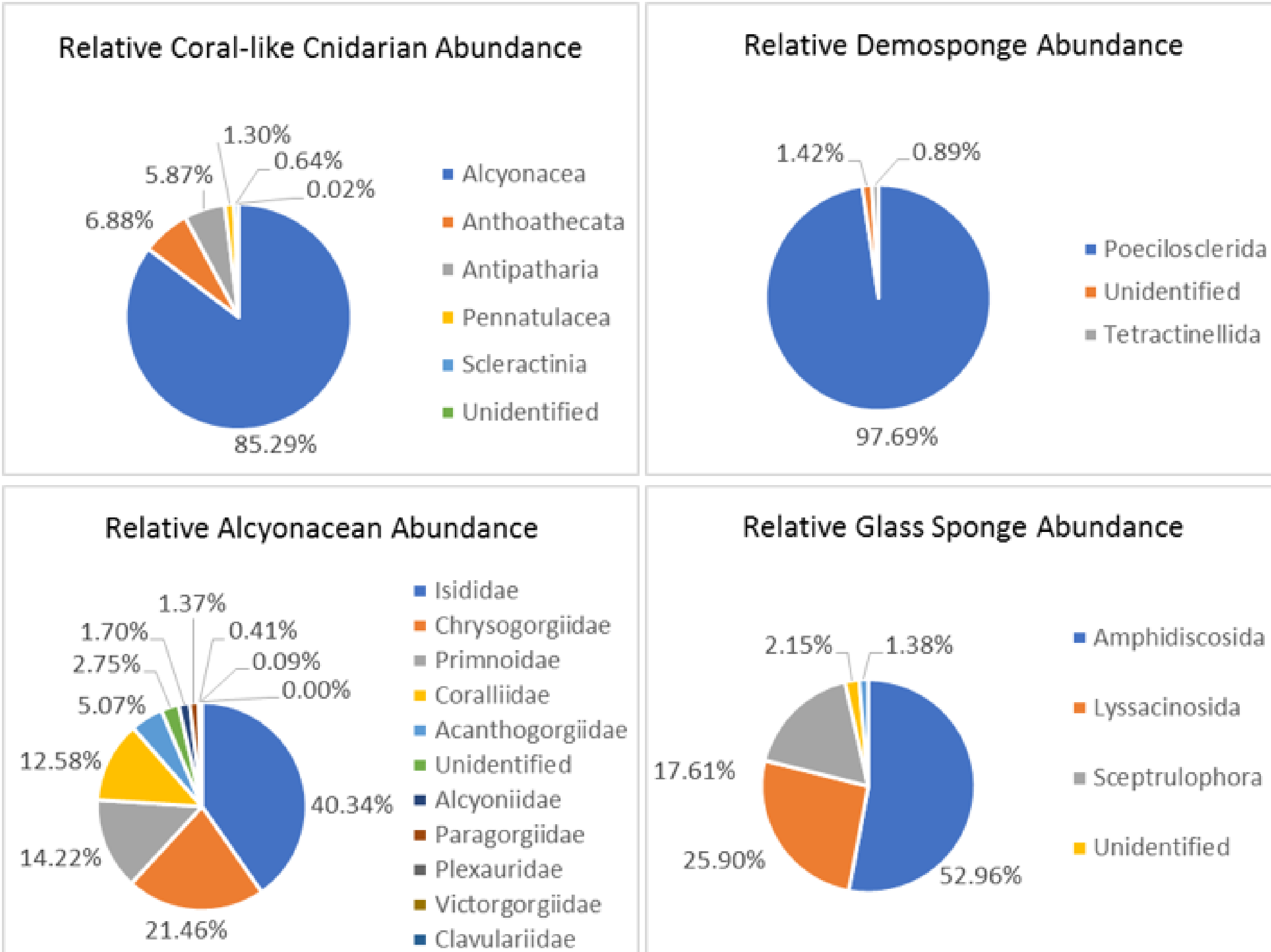

Figure 11. Relative abundance of observed corals and structure-forming hydrozoans (upper left), alcyonaceans (lower left), demosponges (upper right), and glass sponges (Hexactinellida, lower right).

A total of 333 different animal taxa were identified in the video surveys, including the phyla Annelida (4), Cnidaria (135), Porifera (64), Echinodermata (33), Arthropoda (34), Mollusca (4), Ctenophora (2), Chordata (56), and one unidentified animal phylum. A majority of these taxa were identified to genus or a more specific level. Over 85% of the corals observed were from the order Alcyonacea, the gorgonian fan, whip coral, and soft coral groups within the subclass Octocorallia (Fig. 11). The next most abundant corals were the hydrocoral order Anthoathecata (7%) and the black coral order Antipatharia (6%). Among the gorgonians, 8 families accounted for over 99% of the total number counted, with isidids being the most abundant, followed by chrysogorgiids, primnoids, and coralliids.

Although not reflected in Figure 11, more than 98% of demosponges were identified to family in this region. Within the order Poecilosclerida, 85.7% were cladorhizids (0.4% identified to genus, roughly equally split between *Abyssocladia* and *Asbestopluma*), 12.0% were myxillids (all *Stelodoryx* sp.), and 2.2% were dendoricellids (all *Pyloderma* sp.). Within the order Tetractinellida, 95.8% were vulcanellids (all but one identified to the genus *Poecillastra*), and the remainder belonged to the family Geodiidae. The amphidiscosidans were the most abundant group within the glass sponges (class Hexactinellida), followed by lyssacinosidans and sceptrulophorans.

Sponge communities with over 1,000 individuals per km were found at 5 sites, with EX1504L2-16 and EX1603-04 both having a greater sponge density than coral density. Although sponges contributed substantially to the number of animals observed on the dives, corals were, in most cases, the dominant animals within higher-density communities in this region.

Many unusual animals, likely new species were recorded on video. Almost all new descriptions of species are based on careful examination of collected specimens. At this point, it is difficult to determine the number of new species collected during the dives since many have not been carefully examined by taxonomic specialists. Initial identifications of these animals are now being reviewed and will continue to be amended or corrected over the next few years. Estimates of new species from both imagery and collections were 69 for EX1504L2 and 13 for EX1603, a total of 82 for this region. With the exception of the associates, all primary biological specimens were collected because they were potentially either new species or new records for this region. Figure 12 shows an image of *Crypthellia kelleyi,* a newly described species of stylasterid hydrocoral (Cairns 2017). Cairns (2018) also described a new species of primnoid, *Narella virgosa*, collected in this region as well as from the Johnston Atoll and MHI-Musicians seamounts region. However, most new species descriptions from this region have not yet been published due to the length of time that process usually requires. One example of a description currently in process is shown in Figure 12. This glass sponge is being examined by Konstatin Tabachnick at the Shirshov Institute in Moscow and will be a new species in the genus *Lophocalyx* (Tabachnick pers. comm.). The colony shown is also noteworthy because it was reported to be the largest sponge colony ever found in the world (Wagner and Kelley 2017).

Figure 12. A newly described species of stylasterid hydrocoral, *Crypthellia kelleyi* (left), and a potential new species of glass sponge in the genus *Lophocalyx* (right) currently being prepared for publication. Both were collected in PMNM during EX1504L2.

Other noteworthy sponge collections included a potential new species of cladorhizid demosponge and the first confirmed records of the glass sponge genera *Hyalonema*, *Pleurochorium*, and a different species of *Lophocalyx* in the Hawaiian Archipelago. These may also be new species once they have been more thoroughly examined.

Two of the associate animal collections that are notable here because they are new records of genera as well as potential new species are the ctenophore genus *Tjalfiella* and the sea star *Pythonaster*, the latter being a suspected predator of glass sponges (Mah, pers. comm.).

American Samoa and Cook Islands Summary

(Excerpted from "A Report to the NOAA Deep-Sea Coral Research and Technology Program April 3, 2019. A Characterization of the Coral and Sponge Communities in American Samoa and the Cook Islands from *Okeanos Explorer* Surveys Between Feb 8 and May 3, 2017").

Analyses of data extracted from video imagery resulted in baseline characterizations of large-scale, high-density deep-sea coral and sponge communities. High-density communities are defined as having at least 3,000 combined coral and sponge counts per kilometer with very high-density communities having over 10,000 counts per kilometer. Moderate-density communities are defined as those with 1,000–2,999 combined counts per kilometer, and low-density communities are those with less than 1,000 combined per kilometer. Using these definitions, only 2 of the 15 sites surveyed in this region can be characterized as having high-density communities. One site along a western ridge of Swains Island had a very high-density community of corals and sponges (i.e., more than 15,000 individuals/km), dominated by stony coral fans and whip black corals (Table 6; Fig. 13). The other site, in relatively shallow waters along a prominent eastern ridge off Rose Atoll, had a high-density coral and sponge community of nearly 4,000 individuals/km comprised primarily of nephtheid soft corals, dendrophylliid stony corals, and black coral fans. Corals and sponges were found in moderate densities during EX1705-03 and EX1702-07 and low densities for 10 of the 11 other dives (Table 6).

The moderate- to high-density coral and sponge communities were scattered throughout the region (latitudes 4.6 °S to 14.5 °S) and at average depths ranging from 251 to 2,153 m. The very high-density coral and sponge community was documented in depths between 891 and 1,162 m in the first dive of EX1703. Only one other dive (EX1702-09 at Vailulu'u Volcano) surveyed the seafloor at a depth that minimally overlapped the shallow end of this range; that dive had the lowest density of corals and sponges in the region. The high-density community at Rose Atoll (EX1702-10) was seen in shallower depths ranging from 310 to 679 m. Two dives (EX1702-02 and EX1702-13) explored similar depths, but the corals and sponges were about 90% less dense. The other 7 sites with low-density coral and sponge communities were deeper (2,336 to 3,928 m) than sites with moderate- to high-density communities, which may indicate a depth limit to dense communities in this region. In fact, one dive surveyed the same ridge off Rose Atoll that had the high-density community (3,980 sponges and corals/km) at 365 m, but only 520 individuals per km were seen during the deeper dive (EX1702-03) at 2,413 m. With the highest-density community observed at an average depth of 1,012 m and a gap in survey effort between 1,162 and 1,900 m, additional surveys are needed between 1,000 and 2,000 m to determine whether this depth range is particularly suitable for the formation of high-density communities in this region.

The conditions at the two high-density sites revealed no clear patterns to characterize the optimal environments to support large-scale, high-density coral and sponge communities. The community at the Swains Island site was in moderately deeper waters, ranging from 891 to 1,162 m, as compared to the shallow site (310–679 m) off Rose Atoll. Corals and sponges in the densest community were found in the survey with the lowest average dissolved oxygen (DO) level in the region, but that DO level (3.75 mg/L) was average for very high-density communities and above average for high-density communities found during other CAPSTONE expeditions. The intermediate DO level (4.56 mg/L) at the high-density Rose Atoll location was similar to the levels recorded at several of the low-density sites in this region (Table 6). The average temperatures for the two high-density communities ranged from 4.4 °C at Swains Island to 15.2 °C at Rose Atoll. Another shallow site off Taena Bank (EX1702-13) with similar environmental conditions to the shallow-water site at Rose Atoll supported approximately one-tenth of the animals.

Table 6. Summary of animal densities and environmental parameters at each dive site. Note: the CTD failed for a portion of EX1702-07; some temperature and oxygen values were not recorded.

Dive #	Location	Depth (m)	Porifera/km	Cnidaria/km	Combined/km	Avg Depth (m)	Avg Temp (°C)	Avg O2 (mg/l)
EX1703-01	Swains Island	891-1162	220	15050	15270	1012	4.4	3.75
EX1702-10	Rose Atoll	310-679	170	3810	3980	365	15.2	4.56
EX1705-01	Aunu'u Unit of National Marine Sanctuary American Samoa	213-289	570	2300	2870	251	19.2	5.05
EX1705-03	Te Kawhiti a Maui Potiki	2082-2221	120	1680	1800	2153	2.0	3.76
EX1702-07	Moki Seamount	1903-2117	10	1390	1400	1978	2.1	4.32
EX1702-12	Malulu Seamount	2336-2468	690	110	800	2374	1.9	4.49
EX1702-11	Seamount D	2853-2997	590	140	740	2967	1.7	4.63
EX1702-03	Rose Atoll	2345-2529	110	420	520	2413	1.9	4.48
EX1702-13	Taena Bank	193-457	40	430	480	320	15.2	4.44
EX1702-06	Utu Seamount	2874-3034	130	200	320	2939	1.7	4.46
EX1702-02	Ta'u Unit of National Marine Sanctuary of American Samoa	343-505	230	90	310	422	10.6	3.86
EX1702-08	Utu Seamount	3825-3928	140	10	150	3871	1.5	4.99
EX1702-05	Leoso Seamount	3650-3770	130	0	140	3706	1.5	4.90
EX1705-02	Te Tukunga o Fakahotu	2441-2494	70	50	110	2468	1.8	4.18
EX1702-09	Vailulu'u Volcano	680-732	30	10	40	704	5.7	4.86

Similar to high-density communities found elsewhere, the 10 most abundant taxa at each site accounted for the vast majority of the corals and sponges recorded; however, the community composition differed among sites. The dive at Swains Island (EX1703-01) revealed a very dense community of corals and sponges with more than 15 individuals per meter of survey track, consisting mostly of *Enallopsammia rostrata* fans and black corals in the genus *Stichopathes*, and to a lesser extent of other stony corals, glass sponges (including farreids such as *Lonchiphora* sp. and *Farrea* nr. *occa*), and gorgonians (plexaurids and chrysogorgiids). This community characterized 99.5% of all corals and sponges counted at that site (Fig. 14). In contrast, the dive at Rose Atoll (EX1702-10) had a dense community dominated by soft corals (genus *Scleronephthya*), dendrophylliids, and black corals (*Parantipathes* sp.). Demosponges and euretid glass sponges were also present at lower abundance along with octocorals like isidids and acanthogorgiids, small hard corals (including *Polymyces* sp.), and mushroom corals (*Pseudoanthomastus* sp.). These top 10 taxa represented over 98% of the coral and sponge community counts. The difference in community structure between these two sites may be the consequence of the dissimilarity in their environment, such as average depths, temperatures, and dissolved oxygen levels (Table 6).

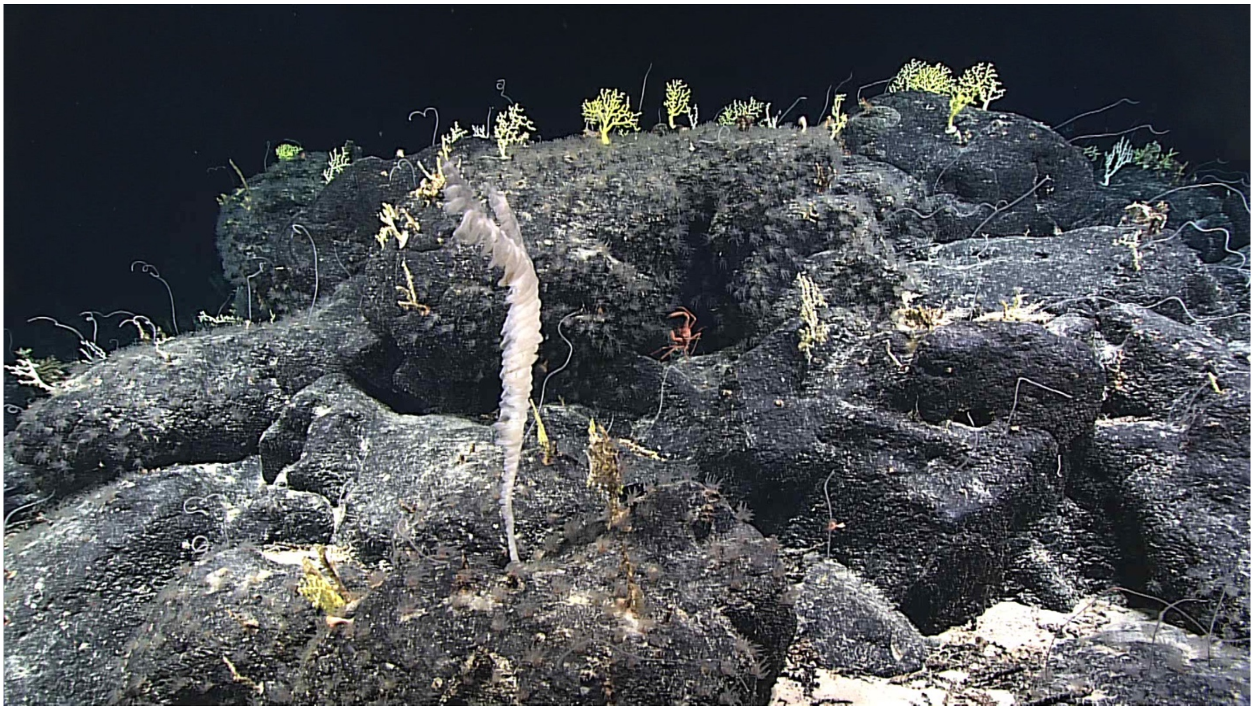

Figure 13. Swains Atoll high-density community of Enallopsammia and Stichopathes.

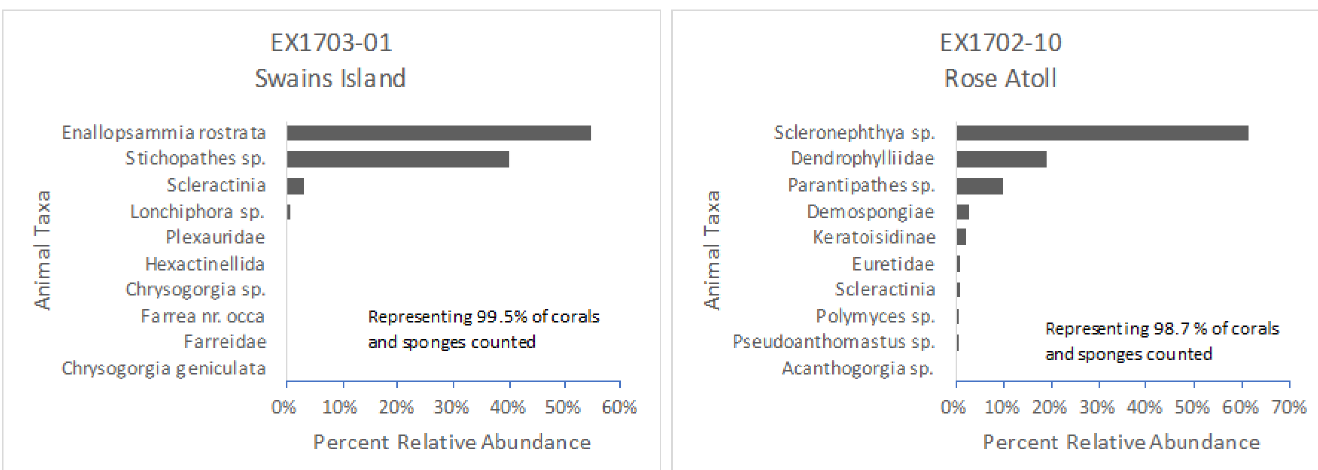

Figure 14. The percentage of total counts for the 10 most numerous taxa of corals and sponges observed at high-density sites found in this region.

Five of the 15 dives in the American Samoa and Cook Island region occurred on ridges, including the two dives with high-density coral and sponge communities. This observation supports the contention that ridges are favorable sites for the formation of high-density communities. However, one of the surveyed ridge sites had only moderate coral and sponge densities and the other two sites contained sparse quantities, demonstrating that the presence of ridge topography alone does not guarantee the formation of large-scale, high-density coral and sponge communities.

Substrate consolidation and depth are two factors that appear to influence the development of large-scale, high-density coral and sponge communities on ridges. The preference for bedrock and large boulders as contact substrates for most corals and sponges was evident in this region (Table 7) as well as other locations surveyed during CAPSTONE. Cobbles and sediment on ridges are not suitable settlement areas for many slow-growing corals and sponges because attachment surfaces are likely to shift, causing colonies to topple which can result in damage or death. Areas consisting primarily of sediment would, therefore, presumably support fewer corals and sponges. The summit of one ridge surveyed during EX1705-03 consisted of large areas of sediment. Nearly three-quarters of the coral and sponge community, which consisted mostly of bamboo corals and euplectellid glass sponges, were observed in areas where sediment was the predominant substrate available, yet not one was attached to the sediment. The moderate quantity of corals and sponges on this ridge may have been higher if a greater portion of the substrate available was consolidated rock. An otherwise suitable ridge may occur at a depth that is unfavorable for coral and sponges' survival. No moderate- or high-density communities were seen at depths greater than 2,300 m in this region. As mentioned earlier, two dives (EX1702 Dives 3 and 10) surveying the same ridge off Rose Atoll revealed a high-density community in shallow waters and a low-density community in the deeper location.

Table 7. Summary of contact or attachment substrate for different types of corals and sponges.

Phylum	Class	Order	Bedrock	Boulder	Cobble	Pebble	Sediment	Biological
Cnidaria	**Anthozoa**	Alcyonacea	91.8%	4.7%	0.5%	0.0%	0.0%	3.0%
		Antipatharia	99.8%	0.1%	0.0%	0.0%	0.0%	0.0%
		Pennatulacea	0.0%	50.0%	50.0%	0.0%	0.0%	0.0%
		Scleractinia	98.2%	1.5%	0.1%	0.0%	0.1%	0.1%
		Unidentified	95.4%	4.6%	0.0%	0.0%	0.0%	0.0%
	Hydrozoa	Anthoathecata	33.3%	66.7%	0.0%	0.0%	0.0%	0.0%
Cnidaria Total			**96.9%**	**2.0%**	**0.2%**	**0.0%**	**0.0%**	**0.9%**
Porifera	**Demospongiae**	Poecilosclerida	13.5%	77.7%	2.7%	0.7%	0.0%	5.4%
		Tetractinellida	82.8%	15.6%	1.6%	0.0%	0.0%	0.0%
		Polymastiida	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
		Unidentified	95.3%	3.8%	0.0%	0.5%	0.0%	0.5%
	Hexactinellida	Amphidiscosida	48.5%	34.8%	6.1%	0.0%	1.5%	9.1%
		Lyssacinosida	84.5%	13.8%	1.3%	0.0%	0.3%	0.3%
		Sceptrulophora	87.8%	7.5%	0.7%	0.0%	0.0%	4.1%
		Unidentified	80.4%	10.9%	4.3%	0.0%	0.0%	4.3%
	Unidentified	Unidentified	66.7%	0.0%	0.0%	0.0%	0.0%	33.3%
Porifera Total			**74.8%**	**20.9%**	**1.6%**	**0.2%**	**0.2%**	**2.4%**
Grand Total			**95.3%**	**3.4%**	**0.3%**	**0.0%**	**0.0%**	**1.0%**

Another potentially important environmental factor that was not quantified in these dives is current velocity. Ridge features or rugose surfaces with boulders and ledges tend to locally accelerate currents, which could enhance the flux of dissolved and particulate organic matter to filter-feeding organisms. Higher localized currents could also prevent settling of sediments to preserve exposed hard substrates to which sessile animals can attach.

Seven of the 15 dives conducted in this region took place within the National Marine Sanctuary of American Samoa (NMSAS), including three within Rose Atoll Marine National Monument. A detailed analysis of the animals recorded within this monument unit is beyond the scope of this report; however, the two high-density sites were within the sanctuary boundaries and one (EX1702-10) was in the monument. This section does provide some basic summary charts and tables of the corals, sponges, and their associated fauna found in this region. Pie charts show the relative abundances of various groups of corals and sponges (Fig. 12). Detailed tables providing the counts for corals, sponges, and their associates for each species or lowest possible identification are available in the regional report.

The overall composition of coral communities in the American Samoa and Cook Island region was very distinct from other regions surveyed during CAPSTONE. Nearly three-quarters (73.26%) of the corals observed in the American Samoa and Cook Island region were hexacorals in the orders Scleractinia and Antipatharia (Fig. 12), unlike other regions where hexacorals contributed to less than one-quarter, and often less than 15%, of the corals counted. The most common families were Dendrophylliidae and Antipathidae, comprising more than 92% of the hexacorals counts. Alcyonaceans, which were the dominant order in all other regions, consisted of only one-quarter of the coral counts in this region. Additionally, the dominant alcyonacean family (Nephtheidae) was a soft coral whereas gorgonian families dominated elsewhere. Isidids and chrysogorgiids, along with soft corals in the family Nephtheidae, accounted for over 93% of alcyonaceans, but nephtheids were only observed during one dive (EX1702-10) and represented nearly half of all the alcyonaceans seen in the region. The relative abundance of coral families is heavily influenced by the low sample size of dive sites and the low occurrence of high-density beds. Most of the coral counts came from the two dives with high-density communities. Since every dive exhibited unique and different communities, it is possible that other important coral taxa have not yet been documented.

Coral abundance was the dominant factor in characterizing the overall density for each site. The two sites (EX1702-11 and EX1702-12) with the greatest abundance of sponges (590–690 individuals/km) had few corals (≤ 140 individuals/km) and are considered low-density communities (Table 4). The relative abundance of sponges was less than 10% of the coral abundance in the region. Demosponges accounted for 39% of the sponges documented, nearly half of which were not even identified to order (Fig. 15). In contrast, more than 93% of the glass sponges were identified to family (Table 7). Euplectellids, rossellids, and aulocalycids in the order Lyssacinosida contributed to a relative abundance of 60% of glass sponges. Figure 16 shows images of some of the corals and sponges observed in this region.

The most common animal phyla to associate with corals and sponges in this region were echinoderms, arthropods, and cnidarians. Approximately 86% of the associates, primarily feather stars, were echinoderms. More than 3,500 comatulid crinoids, including a small number identified as *Psathyrometra* sp., were seen on bamboo corals (isidids) in one dive (EX1705-03). Crinoids were also observed in smaller numbers on coralliid, chrysogorgiid, and primnoid octocorals; dendrophylliid hexacorals; as well as aulocalycid, euplectellid, rossellid, pheronematid, auloplacid, and euretid sponges. Ophiuroids, the next most abundant group of echinoderms, were again observed primarily on isidids, but also associated with other corals and sponges. Arthropods accounted for approximately 7% of the associates identified. The most abundant were poecilasmatid barnacles on isidids, although it is unclear if the barnacles simply settled on damaged parts of the colonies. Similar to other regions, squat lobsters were a common associate of corals, and in particular an unidentified species of *Uroptychus* was often found to associate with chrysogorgiids. Amphipods, which were often undercounted due to their small size, and shrimp in the genus *Lebbeus* were the most abundant arthropods associating with sponges. As for cnidarian associates, zoanthid and anemone hexacorals were the dominant groups, almost all found on corals.

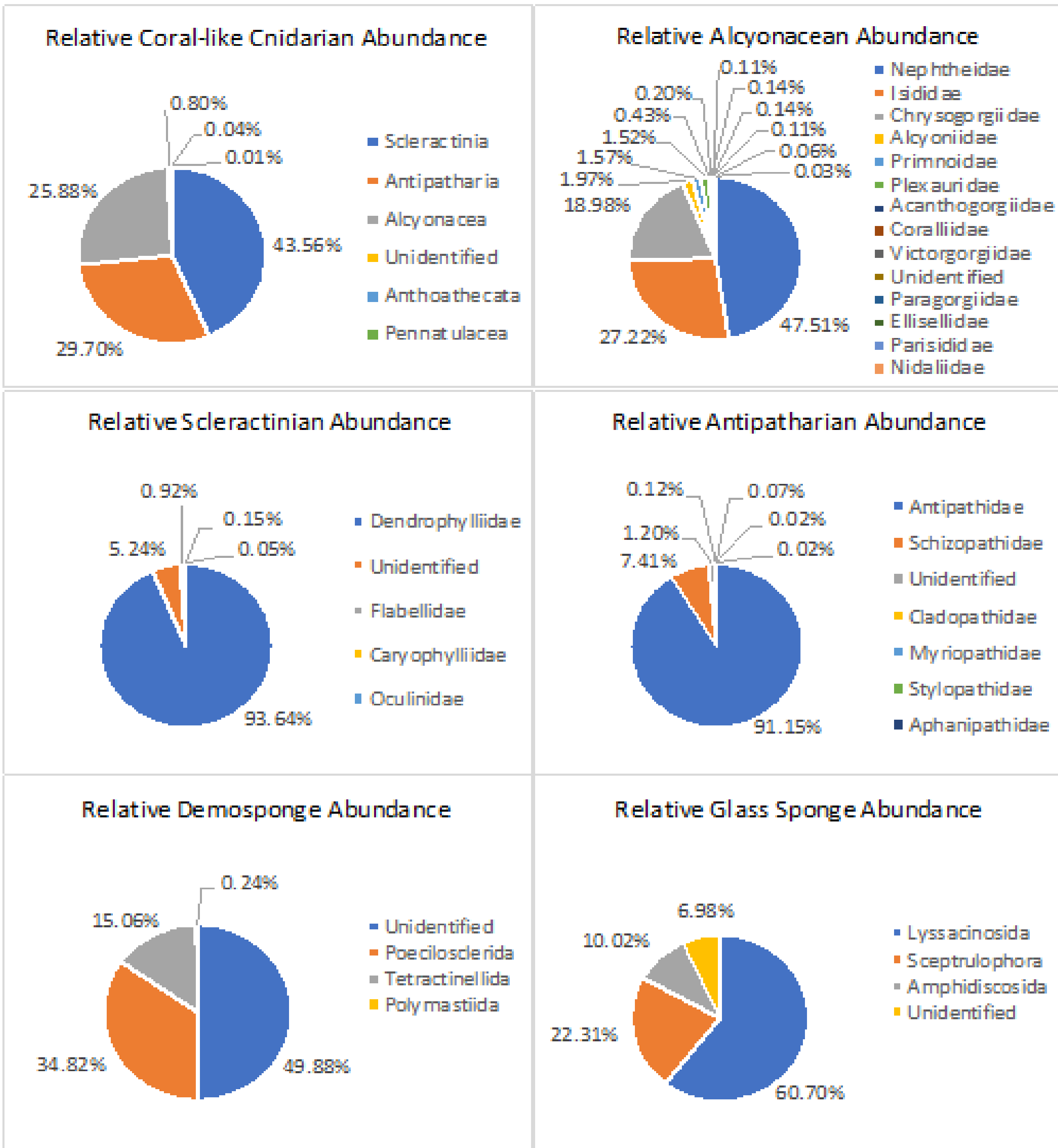

Figure 15. Relative abundance of observed corals and structure-forming hydrozoans (upper left), alcyonaceans (upper left), scleractinians (middle left), antipatharians (middle right), demosponges (lower left), and glass sponges (Hexactinellida, lower right).

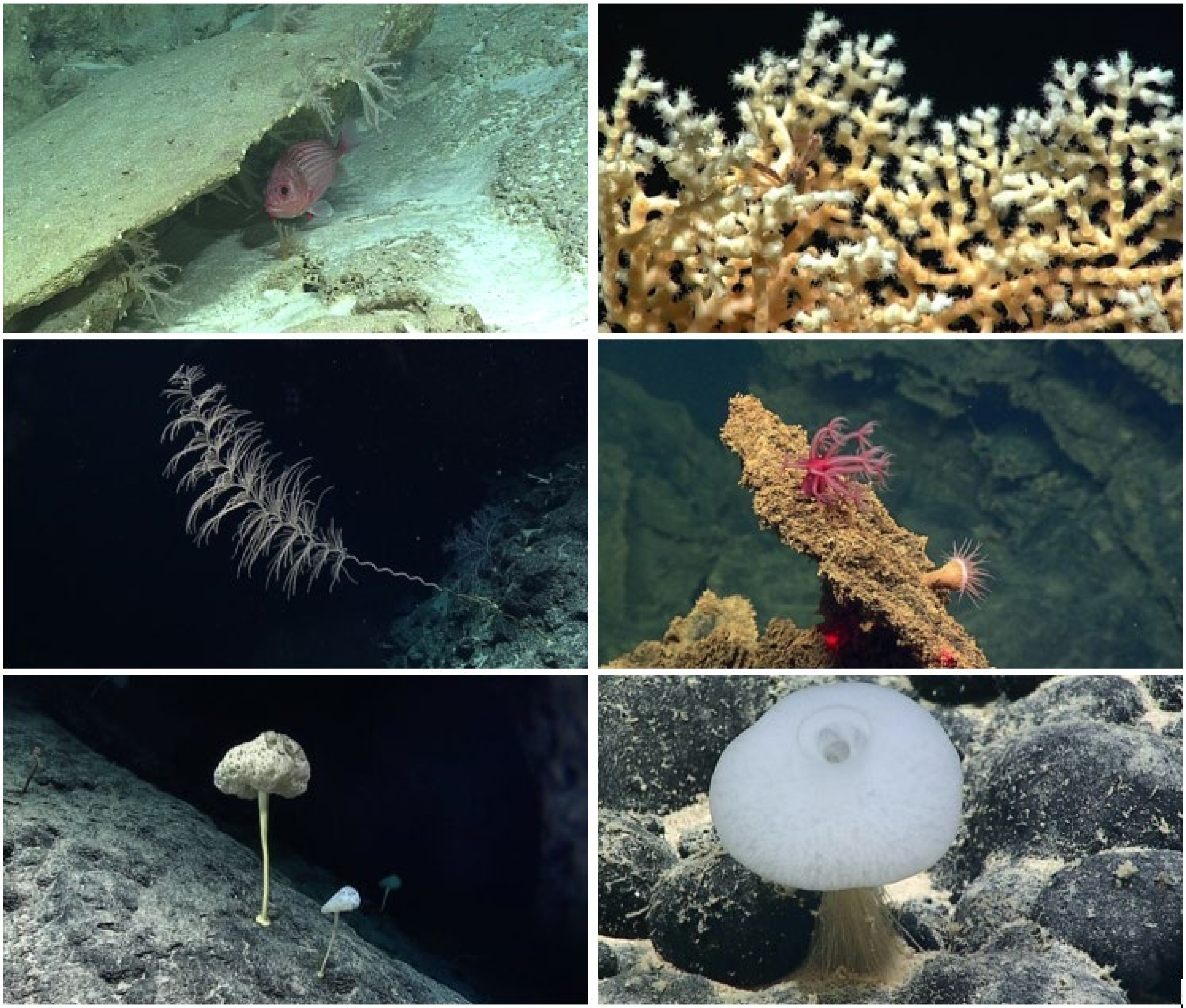

Figure 16. Representative biological observations in the American Samoa region, including soft octocorals at ~330 m (top left), a stony coral with associate squat lobster at ~286 m (top right), Iridogorgia sp. at ~2,037 m (middle left), a mushroom coral and anemone observed in Vailulu'u crater (middle right), potential new species of *Bolosoma* at ~2,420 m (bottom left), and *Hyalonema* sp. at 3,934 m (bottom right).

Distinct communities were identified on seamounts which appeared to be structured by environmental factors that vary with depth. Four shallow dives were conducted at precious coral depths: EX1702-02, EX1702-10, EX1702-13, and EX1705-01. The communities at these sites ranged from sparse to dense populations of corals. Soft coral nephtheids and stony coral dendrophylliids dominated the corals counts for these dives, most of which were recorded at the high-density site. The black coral family Schizopathidae was the third most adundant family at these dive sites, and black corals were present at all four sites in varying degrees. Bamboo corals were only seen at the high-density site (EX 1702-10) and represented 2% of the corals and sponges counted. No coralliids were recorded at these depths in this region, though 7 colonies of *Hemicorallium* were found at depths of more than 2,000 m.

One other relatively shallow dive (EX1702-09) at depths of about 700 m aimed to characterize the biological communities associated with active hydrothermal venting in the crater of Vailulu'u volcano, as well as the biological communities in areas of different age in the central cone of the volcano. The precipitation of particles from hydrothermal venting in the volcano's crater significantly impaired the visibility of the ROV. Only mushroom soft corals (family Alcyoniidae) and demosponges (family Cladorhizidae) were observed in low densities at this site.

Three dives explored the seafloor at depths between 1,000 m and 2,300 m and found moderate- (EX1702-07 and EX1705-03) to very high-density communities (EX1703-01). While the dense community of *Enallopsammia rostrata* fans and black corals in the genus *Stichopathes* dominated the observations at these depths, bamboo corals and chrysogorgiids also were important families, contributing to 13% of the overall counts.

The communities in the dives surveyed in deeper than 2,300 m (EX1702-03, EX1702-05, EX1702-06, EX1702-08, EX1702-11, EX1702-12, and EX1705-02) were different from shallower communities, with sponges becoming more important constituents. Sponges were nearly twice as abundant as corals at these depths. Euplectellid glass sponges, chrysogorgiid octocorals, and myxillid demosponges were the most abundant families, accounting for more than 60% of the total sponge and coral biomass. More surveys are needed to provide a better understanding of the full range of deep-water communities in the region.

Many unusual animals were recorded on video that are likely new species; however, almost all new descriptions of species require careful examination of collected specimens. The ROV collected 52 coral, sponge, and associated animals as specimens in the American Samoa and Cook Island region. Most of the specimens were collected on the basis of being a potential new species and/or new record expanding the range of existing species to the region. Figure 17 shows two newly-described species of primnoid corals from the collections in this region: *Paracalyptrophora spiralis* and a sparsely-branching form of *Calyptrophora distolos* (Cairns 2018). The holotype specimen of *Calyptrophora distolos* is an unbranched colony collected during a different CAPSTONE expedition to the Marianas. Specimens that are likely new species and were collected but not examined to date include an anemone in the genus *Alicia*, the nephtheid in the genus *Scleronephthya*, a glass sponge in the genus *Lonchiphora*, and several crinoids.

Figure 17. Newly described primnoid species from CAPSTONE expedition to American Samoa. The holotype specimen of *Paracalyptrophora spiralis* (upper) and the paratype specimen *Calyptrophora distolos* (lower).

Johnston Atoll Summary

(Excerpted from "A Report to the NOAA Deep-Sea Coral Research and Technology Program April 2, 2019. A Characterization of the Coral and Sponge Communities in the Johnston Atoll Unit of the Pacific Remote Islands Marine National Monument from *Okeanos Explorer* Surveys Conducted between July 10 and September 30, 2015 and July 7 through August 2, 2017.")

High-density communities are defined as having at least 3,000 combined coral and sponge counts per kilometer with very high-density communities having over 10,000 counts per kilometer. Moderate-density communities are defined as those with 1,000–2,999 combined counts per kilometer, and low-density communities are those with less than 1,000 combined per kilometer. Using these definitions, one very high- and 6 high-density communities were found on 7 of the sites in this region, one of which being the shallow dive conducted on the east flank of Johnston Atoll itself (Table 8). These communities resided in waters with temperatures ranging from 1.9 to 7.5 °C and dissolved oxygen values from 1.63 to 3.43 mg/L. Five more sites surveyed contained moderate densities of corals and sponges between 1,000 and 3,000 animals/km.

Table 8. Summary of animal densities and environmental parameters at each dive site.

Dive #	Location	Depth (m)	Porifera/km	Cnidaria/km	Combined/km	Avg Depth (m)	Avg Temp (°C)	Avg O2 (mg/l)
EX1504L4-13	Guyot Ridge, along the northwest end of the Karin Seamounts	1875-2132	1290	15080	16360	1964	2.1	2.91
EX1706-04	Johnston Atoll Site 1	363-581	2020	7830	9850	478	7.5	2.37
EX1706-11	Ridge Seamount	2345-2441	1710	3990	5700	2374	1.9	3.43
EX1706-15	New Seamount 8 Cone	1794-2027	390	5290	5680	1883	2.2	2.96
EX1706-07	Edmondson Seamount	1131-1275	280	3980	4250	1158	4.1	1.63
EX1706-10	Wetmore Seamount East	1970-2078	560	3630	4190	2031	2.1	3.13
EX1504L4-10	Mid Karin Ridge	2080-2324	1690	2400	4090	2218	2.0	3.10
EX1504L4-11	Karin Ridge Top	2040-2170	2750	130	2870	2069	1.9	3.16
EX1706-14	"Keli" Ridge - Southeast Guyot Ridge	2368-2554	2150	390	2540	2419	1.8	3.52
EX1504L4-06	Twin Cones along an extension of Hutchinson Seamount	1493-1696	70	2210	2280	1537	2.9	2.35
EX1504L4-09	South Karin Ridge	1891-1976	730	1080	1800	1924	2.2	2.89
EX1706-13	Sleepy Hollow Seamount - New Seamount Summit Cone	1282-1597	250	1420	1670	1333	3.5	1.96
EX1706-05	"Sally" Seamount	2094-2183	310	600	900	2134	2.0	3.16
EX1706-03	Unnamed Seamount N. of Johnston Atoll	2393-2599	390	340	730	2497	1.8	3.42
EX1706-02	Horizon Guyot	1894-1920	370	150	520	1905	2.1	2.97
EX1504L4-07	Southernmost Cone, a pair of cones on an unnamed seamount	1739-1949	60	440	510	1798	2.5	2.60
EX1706-06	Keli Ridge	1203-1250	180	320	490	1222	4.1	1.76
EX1504L4-08	Lone Cone, a cone feature on an unnamed seamount	1676-2115	30	440	470	1807	2.5	2.61
EX1706-09	Wetmore Seamount	2515-2574	200	240	450	2529	1.8	3.58
EX1504L4-12	Abyssal Ridge, a ridge feature west of Karin Ridge	4053-4238	420	0	420	4125	1.4	4.37
EX1706-08	Pierpont Seamount	1491-1611	80	240	320	1546	3.0	2.32
EX1504L4-05	Deep Twin Ridge, on the south side of the Johnston Seamounts	2083-2429	140	160	300	2179	2.0	3.15
EX1504L4-04	Southeast Johnston	1185-1412	30	200	230	1254	3.5	1.73
EX1706-12	Unnamed Seamount (Seamount 5)	2180-2321	80	130	210	2213	2.0	3.28
EX1504L4-03	Karin Ridge, northeast of Johnston Atoll	3057-3183	110	20	120	3148	1.6	3.83

The community composition and the types of dominant species were different from one site to the next as reflected in the examples shown in Figure 18. The highest-density site, a guyot ridge along the northwest end of Karin Seamounts (1504L4-13) was largely dominated by chrysogorgiids in the genus *Chrysogorgia* that accounted for over 80% of all the coral and sponge counts. The corallid *Hemicorallium* nr. *laauense* was the next most abundant coral at only 3% of the counts. This is consistent with a recurring theme among the high-density communities in all Pacific regions, which is that only a small set of taxa accounted for most of the animals seen during the dive. Over 90% of the animal counts were represented by10 or fewer taxa for each of the 7 high-density communities observed (Fig. 19). Some of the same taxa were present at multiple sites but in general each high-density community had a unique species composition. *Chrysogorgia* sp. was the most common coral at two dive sites (EX1504L4-13 and EX1706-11), *Hemicorallium* sp. dominated two other dive sites (EX1706-04 and EX1706-07), *Candidella gigantea* was the principal species at one site (EX1706-10), and isidids (*Acanella weberi* and an unidentified species in the subfamily Keratoisidinae) dominated two others. The deepest high-density coral site was a ridge seamount at 2,345–2,441 m that was mostly populated by chrysogorgiids and primnoids, along with a variety of sponges such as *Aspidoscopulia* sp., *Poliopogon* sp., *Stelodoryx* sp., and Bolosominae. Antipatharians and scleractinians were nearly absent from this site. In contrast, the shallowest high-density community site was off the flank of Johnston Atoll (EX1706-04) at a depth of 363–581 m.

Figure 18. High-density coral and sponge communities found during EX1706 during Dive 5 (upper left), Dive 7 (upper right), Dive 11 (lower left), and Dive 15 (lower right).

One of the objectives related to O^2 levels was to determine whether precious corals exist in the monument, which had not been previously confirmed. High-density precious red coral (*Hemicorallium laauense*) beds were found in the 350–600 m depth range in the northern end of the Papahanaumokuakea Marine National Monument (PMNM) during submersible dives in 2003. The O^2 minima have been found around 900–1200 m in the vicinity of the monument; the much lower O^2 levels in the Johnston Atoll Unit (JAU) may inhibit precious coral bed development around Johnston Atoll. However, this shallow dive on the flank of the atoll found a spectacular bed of red coral, presumably *Hemicorallium laauense* (Fig. 20), at 400–550 m and in lower oxygen conditions than is present in the northern end of PMNM at this depth.Tentatively concluded from this discovery was that the commercially harvested shallower coralliid species can apparently tolerate a wide range of oxygen levels and in doing so, can potentially colonize a relatively wide latitudinal range in the Central Pacific. This site provided the first documentation of commercially valuable precious corals in JAU.

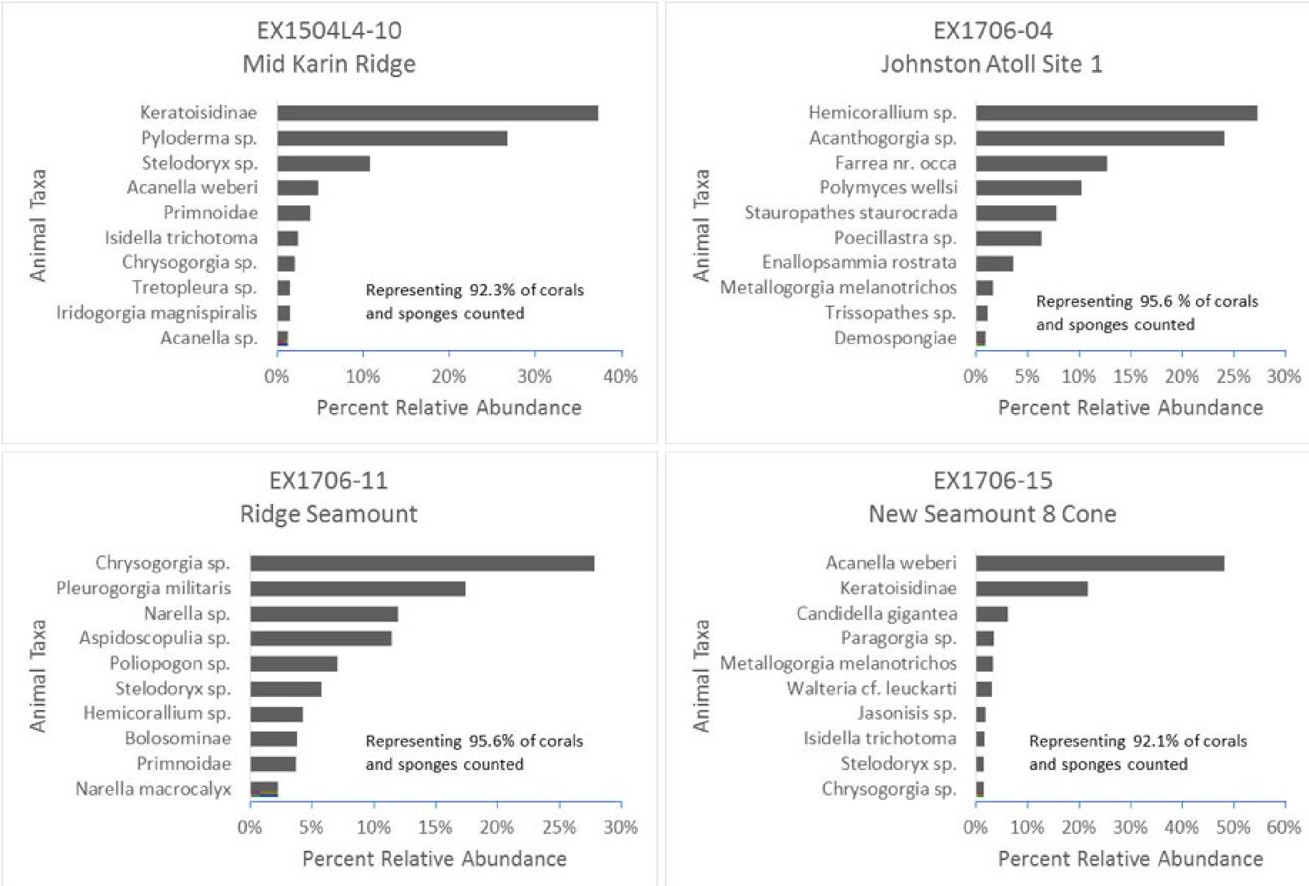

Figure 19. The percentage of total counts for the 10 most numerous taxa of corals and sponges observed at high-density sites found in this region.

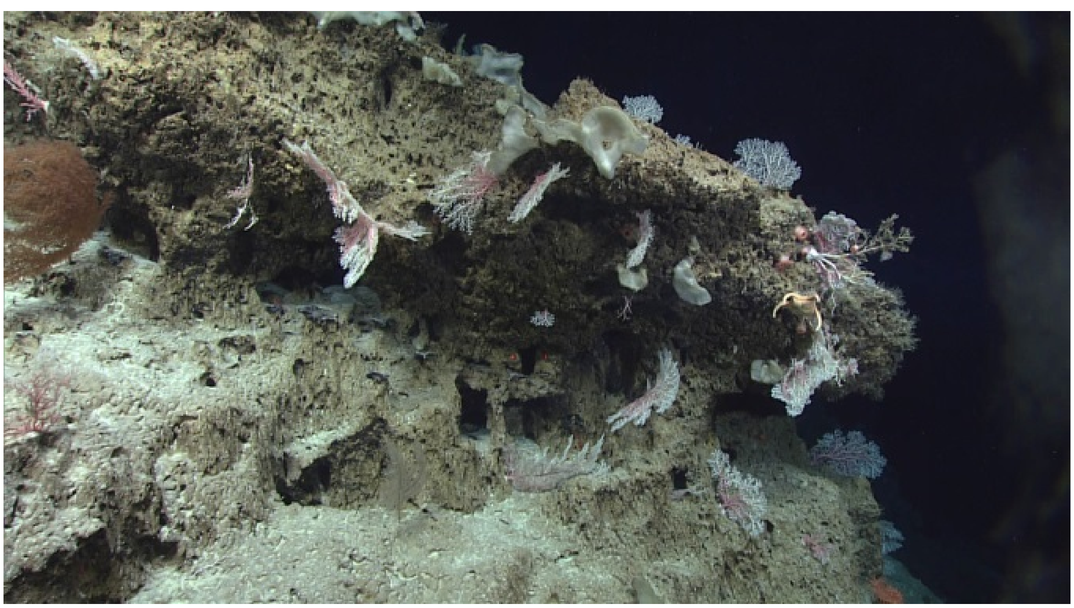

Figure 20. A bed of the precious coral Hemicorallium sp. discovered on slopes of Johnston Atoll during EX1706-04.

Twelve ridge features were surveyed during the 25 dives in the Johnston Atoll region. Three of the 12 ridge sites contained high-density communities confirming that ridges are favorable sites for high-density community formations. However, three of the surveyed ridge sites contained only moderate-density coral/sponge beds and the remainder had very sparse communities. Clearly the presence of ridge topography alone does not guarantee the formation of high-density communities. Besides the current direction and velocity in relation to the ridge, depth and degree of substrate consolidation also factor into coral community structure. For example, dives EX1504L4-03 and EX1504L4-12 were both at ridges with primarily solid bedrock substrate, but below were 3,000 m depth; one was an isolated abyssal ridge north of the atoll (4,053–4,243 m). To date, no high-density beds have been observed below 2,800 meters. Ridge features with higher proportions of unconsolidated substrates like sediment and cobbles as seen in dives 1706-03 and 1504L4-12 may not provide suitable settlement areas for corals to grow and persist over long periods of time. Aside from sea pens, deep-sea corals and sponges require solid substrates to grow. Sessile animals attached to unconsolidated substrates are likely to shift and move during the coral or sponge's lifetime, which can cause colonies to topple and break.

All of the seamounts within the JAU are located in the PCZ; therefore, all 25 dives were conducted inside that deep-sea mining zone. Furthermore, 19 of the dives were conducted on guyots, which are the types of seamounts that are being targeted for future mining activities due to their flat tops and old age. The optimal depth range for mining cobalt-rich Mn crusts in the PCZ is 1000–2,500 m (Hein et al., 2013). All but 4 of the 25 dives were within this depth range, the exceptions being the shallow dive on the flank of Johnston Atoll and three deeper dives ranging from 2,513 to 4,243 m. With the exception of the shallow dive, all were conducted on consolidated, and in parts unconsolidated, substrate consisting of Mn-crusted nodules, boulders, blocks, and pillow lava bedrock. As expected, much of the seafloor appeared heavily coated by Mn crusts and not surprisingly, terraces had more sedimentation than ridges or cone features.

Consistent with findings from other regions, core rock type (i.e., basalt or limestone) does not appear to be a predictor of community density since both low and high-density communities have been found on both limestone and manganese-crusted basalt bedrock. Substrate consolidation does appear to be an important factor for deep-sea corals and sponges since, similar to other regions, the majority of these animals recorded during the dives were observed attached to bedrock (Table 9).

Documenting Mn crust communities has been a CAPSTONE priority for the last 3 years and consequently the ROV pilots spent a considerable amount of time during the dives carefully recording not just corals and sponges, but also many other invertebrates and fishes encountered on crust substrate.

Table 9. Summary of contact or attachment substrate for different types of corals and sponges.

Phylum	Class	Order	Bedrock	Boulder	Cobble	Pebble	Sediment	Biological
Cnidaria	**Anthozoa**	Alcyonacea	93.4%	4.8%	1.8%	0.0%	0.0%	0.0%
		Antipatharia	81.6%	7.5%	10.5%	0.0%	0.1%	0.2%
		Pennatulacea	15.4%	1.4%	0.7%	0.0%	82.5%	0.0%
		Scleractinia	93.1%	4.9%	0.7%	0.0%	0.3%	1.0%
		Unidentified	71.4%	28.6%	0.0%	0.0%	0.0%	0.0%
	Hydrozoa	Anthoathecata	92.3%	0.0%	7.7%	0.0%	0.0%	0.0%
		Leptothecata	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%
Cnidaria Total			**91.9%**	**5.0%**	**2.5%**	**0.0%**	**0.5%**	**0.1%**
Porifera	**Demospongiae**	Poecilosclerida	90.8%	8.1%	1.1%	0.0%	0.0%	0.0%
		Tetractinellida	91.3%	5.7%	1.9%	0.0%	0.0%	1.1%
		Unidentified	53.5%	2.8%	0.0%	0.0%	1.4%	42.3%
	Hexactinellida	Amphidiscosida	43.6%	15.1%	21.8%	0.1%	5.1%	14.3%
		Lyssacinosida	85.1%	10.8%	3.8%	0.0%	0.1%	0.1%
		Sceptrulophora	89.9%	8.3%	1.8%	0.0%	0.1%	0.0%
		Unidentified	52.5%	28.8%	13.6%	0.0%	0.0%	5.1%
	Unidentified	Unidentified	69.8%	21.0%	7.4%	0.0%	0.0%	1.9%
Porifera Total			**83.2%**	**9.7%**	**4.3%**	**0.0%**	**0.7%**	**2.2%**
Grand Total			**89.4%**	**6.3%**	**3.0%**	**0.0%**	**0.6%**	**0.7%**

The data acquired from this cruise will be combined with those from other cruises around the Pacific in 2015 and 2016 to provide the most detailed compilation yet of Mn crust communities in the PCZ.

Previous *Makalii* submersible surveys conducted around the atoll in the 1980s did not document any commercially valuable species, possibly due to the submersible's maximum depth range of 366 m. The communities living below 366 m inside the JAU were first documented in 2015 and 2016 by the *Okeanos Explorer* during EX1504L4 and EX1706. All 25 dives which occurred during these two cruises were conducted within JAU. As mentioned previously, one of these surveyed the shallow flank of the atoll itself for commercially valuable precious corals, a resource managed by NOAA Fisheries that had never been documented before in this region. The atoll is the only location in JAU shallow enough for species under the management of NOAA Fisheries to occur. As a result of this dive, we now know that precious corals do indeed exist in this unit of PRIMNM.

A total of 11 dives were conducted within JAU during EX1504L4 focused primarily on seamounts in the northern and eastern portions of the monument. During EX1706, a total of 14 dives were conducted in JAU, all but three on different features than EX1504L4. Four of the dives during EX1706 were conducted on seamounts where no multibeam data existed and therefore required mapping prior to the dives. These were all located in the previously unexplored southern region of the monument unit. Five other dives during that cruise were conducted on seamounts that had only recently (i.e., Jan 2017) been mapped by the Schmidt Ocean Institute's research ship *Falkor* in the unexplored western part of the monument unit. Two dives were conducted north of Johnston Atoll, one on the southern side of Horizon Guyot and the other on an unnamed guyot first mapped by the *Okeanos Explorer* in 2015. Two other dives were conducted on seamounts mapped by the *Okeanos Explorer* in 2015 but in different locations to further our understanding of deep-sea communities found on ridge topography.

In general, there was substantial overlap in the depth ranges explored during both cruises. The types and abundances of different phyla documented on Mn-crusted seamounts during EX1706 was similar to those of other Capstone cruises focused on these types of features. Cnidarians, particularly octocorals, were the most abundant animals observed followed by sponges (both glass sponges and demosponges), echinoderms (mostly brittle stars), and arthropods (mostly squat lobsters). Coral diversity and abundance were higher on the upper areas of cones arising from flat-tops of guyots as well as on a steep wall. At the latter site, diversity also increased near the top of the wall where there was a transition to the flatter plateau. High-density communities were not observed on other "transition zone" dives (i.e., the second deeper dive on Johnston Atoll itself) although this might have been due to higher observed sedimentation.

An interesting environmental phenomenon is present within JAU whereby the northern and southern halves are potentially divided by large current features flowing east to west in opposite directions. Therefore, it was an objective of EX1706 to dive on more southerly seamounts not explored in 2015 during EX1504L4 and determine whether the different flow features might be expressed by variations in the composition of animal communities seen between the two monument halves at depths between 1,000 and 2,500 m. This specific analysis will need to be conducted outside the context of this report. Another interesting environmental phenomenon is the oxygen minimum pattern in this region of the Central Pacific. Specifically, within the monument, the lowest oxygen levels are reached at approximately 500 m depth in the northernmost seamounts and at 350 m depth in the southern seamounts. This pattern was clear from cursory examination of the CTD data screen during the dives. Any effects from this pattern could only be observed during surveys within this depth range, which in both years, consisted of just a single dive around Johnston Atoll itself. However, 300–800 m midwater transects could detect differences in community composition between northerly and southerly sites depending on the location of the O^2.minima. This was one of the objectives for the four dive sites selected for midwater transects that are not summarized in this report. The consequences of these two environmental phenomena, if detectable, will only be determined after the midwater dive video has been carefully annotated.

Two moderate-density communities were found on dives 13 and 14 during EX1706 that are worth noting (Fig. 21). Dive 13 was conducted on a guyot summit volcanic cone with the ROV landing next to the cone then traversing the flank until it reached the peak. The substrate was sparsely populated with chrysogorgiids, isidids, a few other octocorals, and antipatharians until the ROV reached approximately two-thirds of the way to the peak. At that point, a densely populated community of plexaurid octocorals was encountered and continued right up to the peak of the cone. This dramatic change clearly supports a topographic influence on the structure and density of the community at this site; this pattern has been observed at other sites as well.

Dive 14 was conducted on a guyot ridge in the southeastern part of the monument. The latter half of the dive is denoted by the sudden appearance of a dense community of narrow, needle-like carnivorous sponges (Cladorhizidae, possibly *Asbestopluma* sp.). These were abundant and covered numerous rocky surfaces in evenly-spaced aggregations along the survey line, especially on large boulders and cliffs where currents ran over the edges. Abundance varied across the distance surveyed; higher densities were observed near areas of high current flow while lower densities were observed away from these areas. In one location toward the end of the dive, we observed significant numbers of bryozoans and zoanthids mixed in with the sponges creating one of the most unusual communities encountered during CAPSTONE.

Figure 21. Patchy high-density communities found on Dive 13 (left) and Dive 14 (right).

A detailed analysis of the animals recorded within this monument unit is beyond the scope of this report. However, below are some basic summary charts and tables of the corals, sponges, and their associated fauna found in this region. Pie charts show the relative abundances of various groups of corals and sponges (Fig. 22). Detailed tables providing the counts for corals, sponges, and their associates for each species or lowest possible identification are available in the regional report.

Alcyonaceans were by far the most abundance type of coral observed during the dives in this region followed by antipatharians and scleractinians. Within the alcyonaceans, isidids were the most abundant family of gorgonians followed by chrysogorgiids, coralliids, and primnoids. Most of the demonsponges were poeciloscleridans. Within the hexactinellid glass sponges, sceptrulophorans accounted for almost 37% of the counts, followed by lyssacinosidans and amphidiscosidans. *Chrysogorgia* sp. was the most abundant octocoral followed by *Hemicorallium* sp. and isidids in the subfamily Keratoisidinae. Black corals were the most abundant hexacorals; of these, *Umbellapathes and Bathypathes* sp. were the most abundanta.

Cladorhizids, *Pyloderma* sp. and *Stelodoryx* sp. were the most numerous demosponges. The amphidiscophoran *Poliopogon* sp. was the most numerous hexactinellid taxon followed by several genera in the family Euplectellidae. Farreids (*Aspidoscopulia* sp. and *Farrea nr. occa*) were also relatively abundant. As mentioned in other reports, the presence and abundance of these corals and sponges were not ubiquitous across this region but rather strongly site dependent. While some overlap did exist among sites, each dive site had its own distinct community. There were clearly some recognizable patterns in the deeper communities that have been recorded elsewhere. These patterns, such as the abundance of the various octocoral families mentioned above, are likely due to such factors as depth and the associated environmental parameters, particularly oxygen and substrate consolidation. This implies that a reasonable sample size of dive sites could likely provide an adequate proxy for the deep-sea coral and sponge communities within a particular region or a particular substrate type (i.e., consolidated Mn crust) at the family level and perhaps even to genus. However, the sample size would be for each region would need to be determined individually.

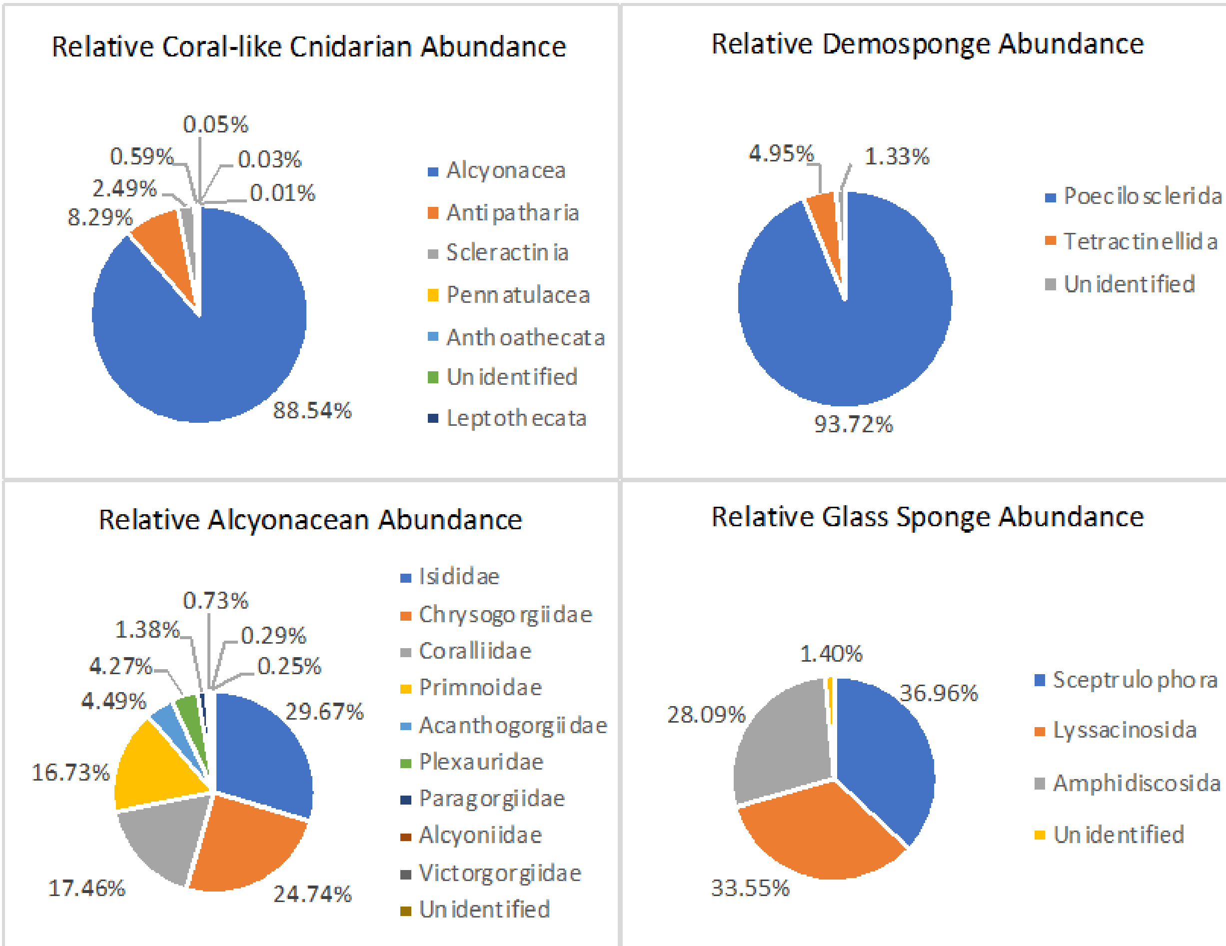

Figure 22. Relative abundance of observed corals and structure-forming hydrozoans (upper left), alcyonaceans (lower left), demosponges (upper right), and glass sponges (Hexactinellida, lower right).

Echinoderms were by far the most abundant type of associate observed followed by arthropods and cnidarians (anemones and zoanthids). All three groups were more prevalent on corals than sponges but were observed on both. Among the echinoderm associates, ophiuroids were the most commonly observed, particularly on plexaurid octocorals. Ophiuroids were also frequently observed on glass sponges, particularly euplectellids. Comatulid crinoids were seen in relatively high numbers on a wide variety of both corals and sponges. Both of these groups of echinoderms are believed to have a commensal relationship with their hosts unlike asteroids, which were generally observed in lower numbers predating on corals and in a few instances glass sponges.

Many different species of arthropod associates were documented in this region with the most abundant being squat lobsters in the order Decapoda. The relationship between squat lobsters and both octocorals and hexacorals is well-known. The most abundant squat lobster was an unidentified species of *Uroptychus* that was commonly observed on chrysogorgiids. Amphipods and gooseneck barnacles (Lepadiformes and Scalpelliformes) were other groups of arthropods commonly observed on corals and sponges, but it is unclear if the latter simply colonized damaged parts of the community. Amphipods in particular were undercounted due to their small size. Other phyla of associates included ctenophores, mollusks, annelid worms, sponges, and foraminiferans. A more detailed analysis of the animals documented to live on corals and sponges in this and other regions will be undertaken by researchers that specialize in these types of associations.

As with other regions, many unusual animals were recorded on video in JAU that are likely new species; however, almost all new descriptions of species are based on careful examination of collected specimens. It is difficult to determine the number of new species since many have not been accessed by taxonomic specialists. With the exception of the associates, almost all of the primary biological specimens were collected because they were either potential new species or were needed to create a new record for this region. As many as 44 of these specimens could represent new species, and most of the specimens from known species represent new range records.

Table 10. Summary of counts of associates by phylum recorded in the Johnston Atoll region.

Associate Phylum	Cnidaria Host	Porifera Host	Total
Echinodermata	2115	529	2644
Arthropoda	452	169	621
Cnidaria	414	43	457
Ctenophora	36	34	70
Mollusca	34	25	59
Annelida	35	19	54
Unidentified Phylum	6		6
Porifera	2	4	6
Foraminifera		1	1

There were at least 4 potentially new species of glass sponges (Hexactinellida) collected including what can only be described as a branching, vaseless *Walteria* sp. (Fig. 23), a branching Tretodictyidae tentatively identified as in the genus *Sclerothamnus*, a strange yellow *Poliopogon* sp. that turned completely black in EtOH, and a farreid that was first photographed in 2015, but was misidentified to a different family until it was collected during EX1706. Unusual cnidarians included a "swimming" ceriantharian, a potentially new species of Paragorgiidae, a black coral in the genus *Lillipathes*, and a bamboo coral only identified as in the subfamily Keratoisidinae.

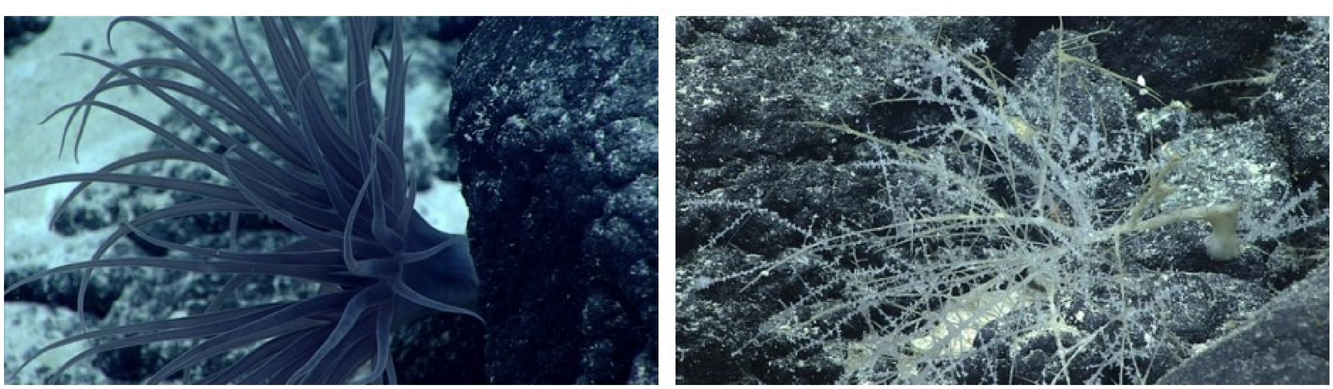

Figure 23. Potential new species of a tube anemone (Ceriantharian, left) and euplectellid glass sponge most closely resembling species in the genus *Walteria* but without an atrial cavity (right).

Wake Atoll Summary

(Excerpted from “A Report to the NOAA Deep-Sea Coral Research and Technology Program February 13, 2019. A Characterization of the Coral and Sponge Communities in the Wake Unit of the Pacific Remote Islands Marine National Monument from *Okeanos Explorer* Surveys Between March 23 and September 11, 2016”)

Very high-density communities are defined as having at least 10,000 combined coral and sponge counts per kilometer; high-density communities are defined as having at least 3,000 combined counts per kilometer. Moderate-density communities are defined as those with 1,000–3,000 combined counts per kilometer; low-density communities are those with less than 1,000 combined counts per kilometer. Using these definitions, one very high- and three high-density communities were found on four of the dive sites: 2, 6, 10, and 11, the last being a shallow dive conducted on the east slope of Wake Island (Table 11). The community composition and the types of dominant species were different from one site to the next. Although Dives 2 and 3 were conducted on adjacent seamounts (Samson and Delilah guyots), Dive 2 discovered a strange community of 2-branched primnoids in the genus *Narella* mixed with antipatharians (*Heteropathes* or *Trissopathes* sp.) and an unusual demosponge dubbed the "Kebab" sponge (an undescribed species of demosponge), which was particularly abundant on the un-named seamount surveyed during Dive 6. The densest groups were observed on the topographic highs. Dive 10 found the most amazing community dominated by huge, very old coralliids (*Hemicorallium* sp.), primnoids (*Calyptrophora* sp.), isidids, and acanthogorgiids mixed in with various other species of corals and sponges. This was perhaps the most spectacular community found during the cruise. Dive 11 found a dense shallow community of precious gold and bamboo corals (*Kulamanamana haumeaae* and *Acanella* sp.) growing on the edge of a terrace or fault block. Thousands of sea pens (*Calibelemnon* sp.) were observed both below and above the edge.

Figure 24 shows example images of several of these communities. The other dive sites had moderate- to low-density communities, again each differing in composition and dominant species. These communities had numerous species of corals and sponges, most of which were observed in lower numbers. The highest density of corals and sponges was observed at Sampson (Beatty) Guyot at depths between 2,176 m and 2,250 m. With a density of 13,590 animals per km, Sampson Guyot (EX 1606-02) was roughly twice as dense as any of the other high-density sites. Sampson (Beatty) Guyot was dominated by cnidarians with the top three taxa representing approximately 80% that included a primnoid, stylasterid, and antipatharian coral. *Narella* sp. corals were the most common and were as abundant as *Lepidopora* sp. and *Trissopathes* sp. corals combined. Two new species described by Stephen Cairns were identified on this dive: *Narella merga*, a bifurcate primnoid with large plate-like scales, and a new species of *Lepidopora* sp. EX1606-10 explored an unnamed guyot south of Wake Island. The survey was conducted at 1,380–1,515 m and observed a gorgonian dominated high-density community where over half the coral and sponge abundance was represented by *Acanthogorgia* sp. The next most abundant coral was *Hemicorallium* sp. Other gorgonian families, such as Isididae and Primnoidae*,* were also abundant but at an order of magnitude less than the two dominant taxa.

Table 11. Summary of animal densities and environmental parameters at each dive site.

Dive #	Location	Depth (m)	Porifera/km	Cnidaria/km	Combined/km	Avg Depth (m)	Avg Temp (°C)	Avg O2 (mg/l)
EX1606-02	Sampson (Beatty) Guyot	2176-2250	460	13130	13590	2213	1.9	3.37
EX1606-10	Unnamed Guyot South of Wake	1380-1515	440	7150	7590	1422	2.8	2.56
EX1606-11	Wake Island East	444-639	50	5710	5760	480	9.0	4.33
EX1606-06	Unnamed Guyot	1976-2230	3340	1170	4510	2089	2.0	3.23
EX1606-07	Lafayette Guyot	1909-2088	290	2170	2460	1970	2.2	3.04
EX1606-03	Delilah Guyot	1843-1984	170	1750	1910	1873	2.2	3.03
EX1606-09	Amakasu Maru No. 1	804-1146	310	840	1150	979	4.2	2.11
EX1606-14	Last Dive Guyot	1209-1283	160	720	870	1240	3.8	2.21
EX1606-01	Alba (Vlinder) Guyot	1986-2319	170	360	530	2134	2.0	3.29
EX1606-08	Wake Island North	746-944	10	320	330	797	5.0	1.80
EX1606-13	Batfish Guyot (unofficial)	3058-3131	160	100	260	3088	1.6	3.99
EX1606-05	McDonnell Guyot West	2466-2582	60	200	250	2505	1.7	3.73
EX1606-12	Revolver Guyot (unofficial)	1145-1267	50	180	220	1214	3.4	2.50

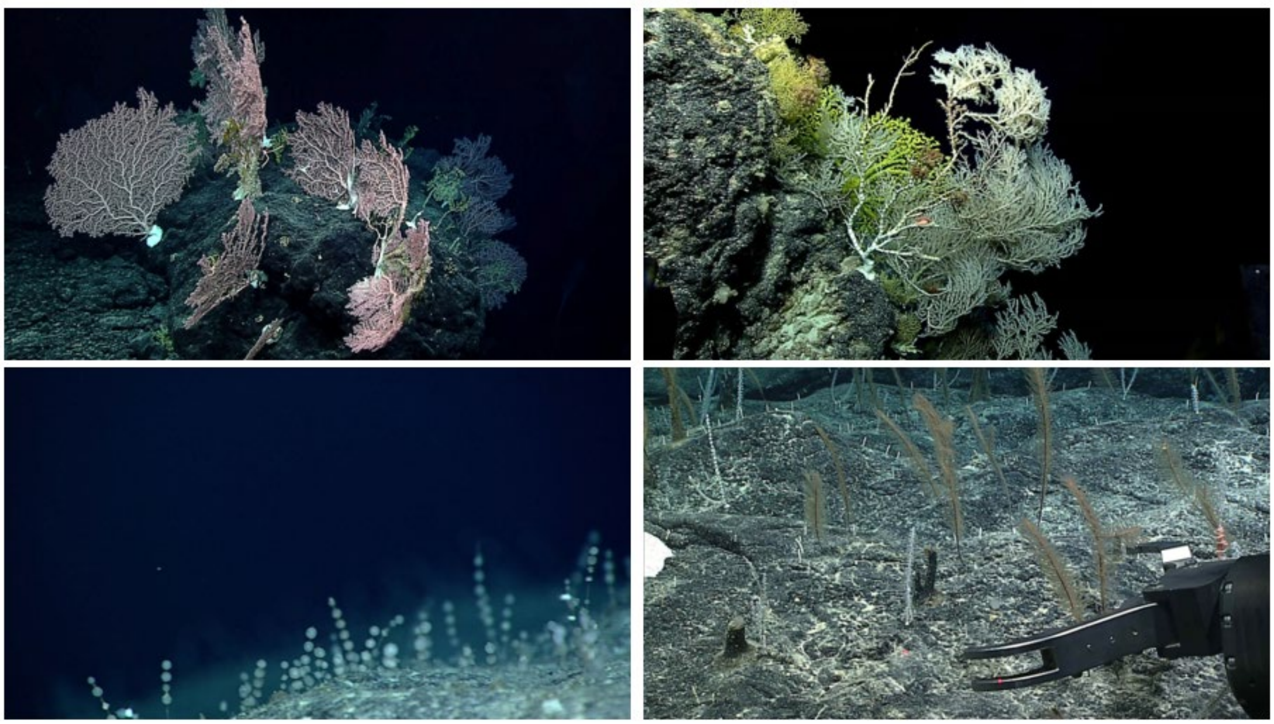

Figure 24. Different types of high-density communities of deep-sea corals and sponges were encountered at a number of the dive sites, including one dominated by large *Hemicorallium* sp. (upper left), a community dominated by *Acanella* sp. being overgrown by the gold coral Kulamanamana haumeaae (upper right), a dense moderately-sized community of "kebab" demosponges (lower left), and 2-branch *Narella* sp. and *Trissopathes* sp. (lower right).

Calyptrophora lyra, a new species of primnoid that was described by Stephen Cairns in 2018, comprised 3.9% of the animals counted. Sponges represented a smaller proportion of animals counted with *Tretopleura* sp., *Farrea* nr. *occa erecta* and *Poliopogon* sp., and other Pheronematidae adding to approximately 5% of the total animal count.

The shallower dive on Wake Island East (EX1606-11) was dominated by pennatulaceans; 71% of the corals and sponges counted were *Calibelemnon symmetricum,* which was an order of magnitude more abundant than any other taxon. Plexaurids, *Anthoptilum* sp., *Stauropathes* sp., and Keratoisidinae were fairly common, each representing ~4–6% of the animal counts. The precious gold coral, *Kulamanamana haumeaae*, was present but at relatively low numbers (~1% of animals counted). Sponges were rarer on this dive. Only one demosponge taxon, *Poecillastra* sp., was represented in the top 10 most abundant animals and constituted only 0.64% of the animal counts. Dive EX1606-06 exhibited a high-density community on an unnamed guyot at depths of 1,976–2,230 m in the Wake Island region. This guyot was unique because the community was dominated by sponges. One type of undescribed kebab-shaped demosponge dominated the substrate and represented nearly 60% of all corals and sponges observed. The hexactinellid, *Tretopleura* sp., made up 8% of observed animals.

Similar to high-density communities found elsewhere, the 10 most abundant taxa at each site accounted for over 94% of the total coral and sponges counted (Fig. 25). The single most abundant species differed at each site and included an acanthogorgiid, a primnoid, a pennatulacean, and a demosponge. The community composition was also unique at each site. Antipatharia were the only group of animals observed in abundance at all 4 high-density sites, although each group was composed differently. The shallowest site surveyed off of East Wake Island (EX1606-11) had the least overlap in species composition, which suggests that depth is an important factor in species composition and stratification.

The depth, dissolved oxygen (DO), and temperature at the three deeper high-density communities ranged from 1,380–2,250 m, 2.6–3.4 mg/L, and 1.9–2.8 °C, respectively. None of these parameters appears to be useful for predicting the presence of high-density communities since the other lower-density communities in this region were found at similar depths, oxygen, and temperature values. Furthermore, data acquired from other CAPSTONE regions indicate that DO values can vary considerably in these communities and are therefore not good predictors of the presence of high densities.

A majority of the dives were carried out on ridge crests along the deeper rift zones, while two dives visited guyot tops, and three dives were carried out in shallow water. The ridge crest dives were generally characterized by thick ferromanganese crusts covering what appeared to be pillow lavas (and tube lavas). On many of the ridge crests, the pillow lavas occurred as concentrated pillow mounds separated by more sedimented areas. The steeper sides of the pillow mounds provided insight into the potential ferromanganese crusts, resulting in estimates of up to several inches.

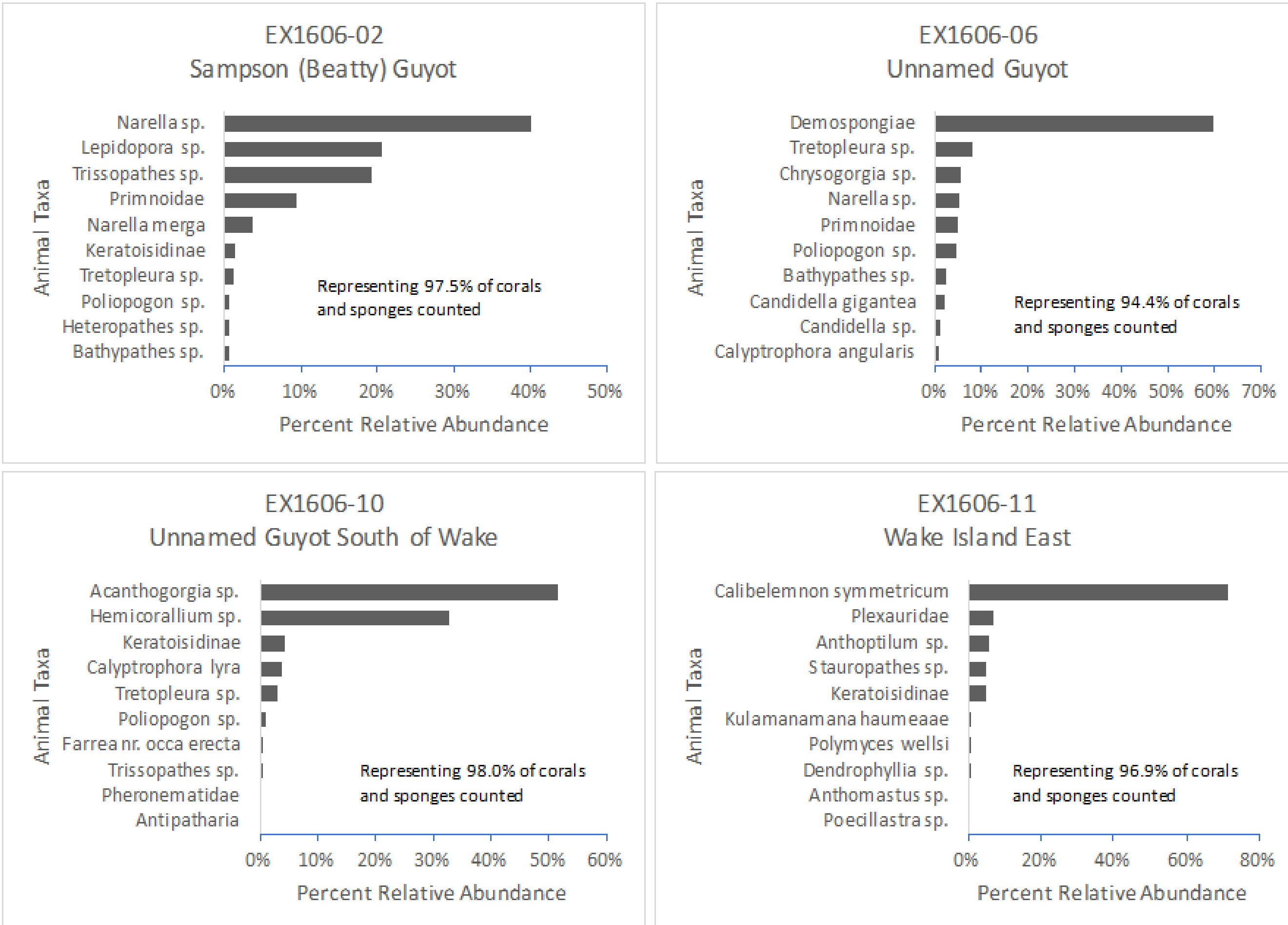

Figure 25. The percentage of total counts for the 10 most numerous taxa of corals and sponges observed at high-density sites found in the Wake Atoll region.

Rift zone ridges were confirmed as sites of large-scale high-density coral and sponge communities during the expedition. However, the surveys also revealed that the presence of a ridge does not guarantee the presence of a high-density community since other factors such as substrate consolidation and depth are clearly important. Eight of the 13 dives conducted in Wake Island were on ridge habitats. Three of the high-density communities discovered (EX1606-02, EX1606-06, and EX1606-10) were found on ridge features, while the shallower East Wake Island dive (EX1606-11) was on protrusion coming off the island flank. The other ridge features explored contained 2 moderate- and 3 low-density communities. The range in animal densities suggests that presence of a ridge feature does not guarantee optimal conditions for coral and sponge settlement and growth. For example, the lowest density community on a ridge feature was Batfish Guyot (EX1606-13), which was surveyed at an average depth of 3,088 m. Large-scale high-density coral and sponge communities have not yet been observed on seamount features deeper than 2,700 meters. Some of the low-density ridges also exhibited a higher proportion of unconsolidated materials such as sediment and cobbles as the primary substrate. Cobbles and sediment on ridges are not suitable settlement areas for slow growing sessile animals, with the exception of sea pens, because attachment surfaces are likely to shift and move during the coral or sponge's lifetime. Moving substrates cause colonies to topple and can result in breakage or death.

Another possible important environmental factor that was not quantified in these dives is current velocity. Ridge features or rugose surfaces with boulders and ledges tend to locally accelerate currents, which could enhance the flux of dissolved and particulate organic matter to filter-feeding organisms. Higher localized currents could also prevent settling of sediments to preserve exposed hard substrates to which sessile animals can attach.

The Wake region is entirely within the PCZ and therefore all of the dives conducted at depths between 1,000 and 2,500 m were relevant to this objective. The first dive of EX1606 took place outside the Wake Monument Unit on a Russian lease block for mining exploration, while the other 12 were carried out within the monument. Ten of the 13 dives took place within the Mn crust depth range and these were all on flat-topped guyots with mainly pillow lavas coated in ferromanganese crust exposed on their lower flanks. Their tops showed increased amounts of carbonate sediment and some revealed post-erosional cones. These cones can either consist of volcanoclastic sediments or pillow lavas, reflecting explosive interaction with seawater or non-explosive submarine eruption. Six of the 7 high- and moderate-density communities were found on this type of substrate, while the shallow high-density community was found on limestone with a higher proportion of boulders and sediment present as primary substrate. Therefore, consistent with findings from other regions, core rock type (i.e., basalt or limestone) does not appear to be a predictor of community density since both low and high-density communities have been found on both limestone and manganese crust basalt bedrock. However, substrate consolidation does appear to be an important factor for deep-sea corals and sponges since the majority of these animals recorded during the dives were observed attached to bedrock (Table 12). Dive sites with lower density communities tended to have a greater proportion of sediment as a primary substrate.

Table 12. Summary of contact or attachment substrate for different types of corals and sponges.

Phylum	Class	Order	Bedrock	Boulder	Cobble	Pebble	Sediment	Biological
Cnidaria	**Anthozoa**	Alcyonacea	89.2%	9.9%	0.7%	0.0%	0.0%	0.1%
		Antipatharia	96.7%	2.2%	0.8%	0.0%	0.1%	0.3%
		Pennatulacea	65.1%	33.4%	0.7%	0.0%	0.7%	0.0%
		Scleractinia	86.4%	13.6%	0.0%	0.0%	0.0%	0.0%
		Zoantharia	18.6%	50.8%	0.0%	0.0%	0.0%	30.5%
		Unidentified	68.0%	32.0%	0.0%	0.0%	0.0%	0.0%
	Hydrozoa	Anthoathecata	89.8%	10.2%	0.0%	0.0%	0.0%	0.0%
Cnidaria Total			**83.9%**	**15.1%**	**0.7%**	**0.0%**	**0.2%**	**0.2%**
Porifera	**Demospongiae**	Poecilosclerida	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Tetractinellida	30.6%	63.9%	0.0%	0.0%	0.0%	5.6%
		Unidentified	97.8%	1.1%	0.0%	0.0%	0.0%	1.1%
	Hexactinellida	Amphidiscosida	86.1%	6.5%	0.6%	0.0%	1.2%	5.6%
		Hexasterophora incertae sedis	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
		Lyssacinosida	72.0%	26.5%	1.4%	0.0%	0.0%	0.0%
		Sceptrulophora	90.8%	7.8%	1.3%	0.0%	0.0%	0.1%
		Unidentified	65.9%	13.6%	4.5%	0.0%	0.0%	15.9%
	Unidentified	Unidentified	82.8%	6.9%	6.9%	0.0%	0.0%	3.4%
Porifera Total			**91.6%**	**6.2%**	**0.6%**	**0.0%**	**0.1%**	**1.5%**
Grand Total			**85.0%**	**13.7%**	**0.7%**	**0.0%**	**0.2%**	**0.4%**

Twelve of the 13 dives conducted in this region took place within the Wake unit of PRIMNM. A detailed analysis of the animals recorded within this monument unit is beyond the scope of this report.

However, this section does provide some basic summary charts and tables of the corals, sponges, and their associated fauna found in this region. Pie charts show the relative abundances of various groups of corals and sponges (Fig. 26). Detailed tables providing the counts for corals, sponges, and their associates for each species or lowest possible identification are available in the regional report.

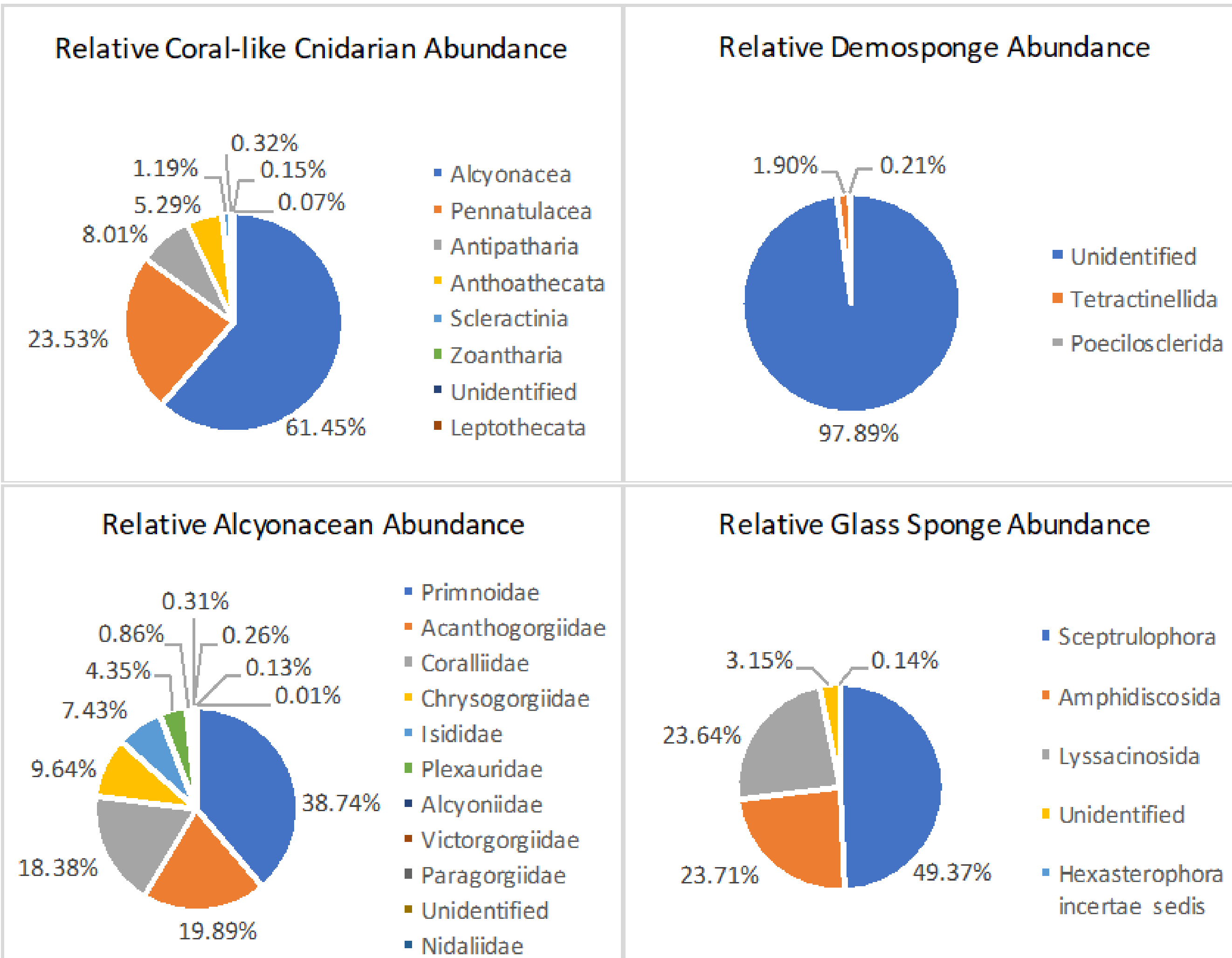

Figure 26. Relative abundance of observed corals and structure-forming hydrozoans (upper left), alcyonaceans (lower left), demosponges (upper right) and glass sponges (Hexactinellida, lower right).

Alcyonaceans were by far the most abundant type of coral observed during the dives in this region followed by pennatulaceans, the latter being mostly the result of a large community of "rock pens" (*Calibelemnon symmetricum*) observed in the shallow dive off the slope of Wake Island. Pennatulaceans were followed by antipatharians. Primnoids were the most abundant family of gorgonians followed by acanthogorgiids, coralliids, chrysogorgiids, isidids, and plexaurids. Most of the demonsponges could not be identified further than class. Within the hexactinellid glass sponges, sceptrulophorans accounted for almost 50% of the counts, followed by amphidiscosidans and lyssacinosidans. *Calibelemnon symmetricum* was the most abundant octocoral followed by *Narella* sp., *Acanthogorgia* sp., and *Hemicorallium* sp. Black corals were the most abundant hexacorals, with the the majority of which were *Trissopathes* sp., *Stauropathes* sp., and *Bathypathes* sp. The tiny stylasterid *Lepidopora* sp. wasthe most abundant structure forming hydrozoan, and because of its size, was undoubtedly undercounted since it could only be clearly identified when the ROV stopped for closeup imagery. Small unidentified demosponges were the most numerous sponges and again because of their size, were undoubtedly grossly undercounted. The sceptrulophoran *Tretopleura* sp. and the amphidiscophoran *Poliopogon* sp. were the most numerous hexactinellids. The presence and abundance of these corals and sponges were not ubiquitous across this region but rather were strongly site dependent. While some overlap did exist between sites, the community at each dive site had its own distinct species composition. There were clearly some recognizable patterns in the deeper communities that have been recorded elsewhere. These patterns, such as the abundance of the various octocoral families mentioned above are likely due to such factors as depth and the associated environmental parameters, particularly oxygen, as well as substrate consolidation. This implies that a reasonable sample size of dive sites could likely provide an adequate proxy for the deep-sea coral and sponge communities within a particular region or a particular substrate type (i.e., consolidated Mn crust) at least at the family level and perhaps even to genus. However, an adequate sample size for each region would need to be determined individually.

Sea anemones (Actiniaria), the most abundant type of cnidarian associates, were observed in association with both corals and sponges. However, the sponge connection is tentative at this point because some tiny cnidarian observed in euplectellid, euretid, and uncinaterid glass sponges is not a confirmed anemone and could be a zoantharian. Larger, more clearly recognizable anemones were seen on a number of different corals, isidids, and primnoids in particular. Zoantharians were the next most abundant cnidarian associate and were observed predominantly on corals rather than sponges. Among the echinoderm associates, ophiuroids were the most commonly observed, particularly on primnoid and coralliid octocorals as well as on a few sponges. Commatulid crinoids were next most abundant, with a higher number of these seen on hexactinellids. Sea stars were observed in lower numbers; several members of this group are known predators of both corals (i.e., *Hippasteria* sp. for example) and sponges (*Pythonaster* sp.). Many different species of arthropod associates were documented in this region; squat lobsters in the order Decapoda were the most abundant. The relationship between squat lobsters and both octocorals and hexacorals is well-known. The most abundant squat lobster was an unidentified species of *Uroptychus* that was commonly observed on chrysogorgiids. Amphipods and gooseneck barnacles (Lepadiformes and Scalpelliformes) were other groups of arthropods also observed on corals, but its unclear if the latter simply colonized damaged parts of the colonies. Amphipods in particular were undercounted due to their small size. Other phyla of associates included annelid worms, tunicates, mollusks, and sponges.

Many unusual animals were recorded on video that are likely new species; however, almost all new descriptions of species require careful examination of collected specimens. At this point, it is also difficult to determine the number of new species collected during the dives since many have not been carefully examined by taxonomic specialists. With the exception of the associates, all primary biological specimens were collected because they were either potential new species or were needed to confirm they were a new record for this region. To date, Dr. Stephen Cairns has described 5 new species of primnoid from collections in this region: *Narella merga*, *N. calamus*, *N. aurantiaca*, *Macroprimnoa ornata*, and *Calyptrophora lyra*. A new species of the stylasterid *Lepidopora* was also identified by Cairns, although a holotype description has not yet been published. Among the sponges, the most unusual was the "kebab" demosponge, which is either a new species or a new record for a sponge previously documented from the Galapagos. It is also worth noting that the commercially important precious coral *Kulamanamana haumeaae* was documented and collected for the first time in this region.

Marianas Archipelago Summary

(Excerpted from "A Report to the NOAA Deep-Sea Coral Research and Technology Program April 02, 2019. A Characterization of the Coral and Sponge Communities in the Marianas Archipelago Region from *Okeanos Explorer* Surveys Conducted Between April 20 and July 10, 2016.")

High-density communities are defined as having at least 3,000 combined coral and sponge counts per kilometer, very high-density communities have over 10,000 counts per kilometer. Moderate-density communities are defined as those with 1,000–2,999 combined counts per kilometer, and low-density communities are those with less than 1,000 combined per kilometer. Using these definitions, 3 very high- and 5 high-density sites were observed in 8 of the dive sites conducted the Marianas region (Table 13). Five additional dive sites contained moderate-density communities, while the remaining 28 dive sites were sparsely populated. In Table 13, the average depth of EX1605L3-22 is not shown since this is both a cultural heritage site as well as a war grave site. N/A in the last 3 dives indicates that there were no corals or sponges observed during the dives; the environmental data and depths are therefore not applicable. There were few corals and sponges observed on the other 3 dives listed above these in Table 13; however, when rounded to a single integer, their counts appear as 0. Figure 27 shows example images of high-density communities encountered in this region, all of which differed in terms of their species composition. The 3 very high-density sites all occurred at relatively shallow depths for cold-water corals, which ranged from 278–655 m. The highest density dive was at Supply Reef (1605L3-06) where a community of demosponges was encountered that was dominated by heteroscleromorphans and other unidentified species. Zealandia Bank had a surprising community that was dominated by the gorgonian Parisis sp. mixed with stylasterid hydrocorals and the gorgoniid *Eunicella* sp. Maug Island was covered with a small yellow scleractinian (Dendrophyllia sp.), which was interspersed with a smaller number of Acanthogorgia sp. and demosponges. Deeper high-density communities on three of the guyots east of the trench revealed abundant octocorals and glass sponges. The deepest of these was observed on Enrique Guyot (EX1605L1-15) around 2,200 m, which was dominated by demosponges followed by *Trissopathes* sp., Keratosidinae, and *Pleurogorgia militaris.* This location had the lowest average temperature of the high-density communities at 1.9 °C. Dissolved oxygen concentrations were above 3 mg/L for almost all the high-density coral communities with the exception of Farallon de Medinilla 2, which had an average DO around 2.48 mg/L. Oxygen and temperature co-vary with depth, and there may be interactions between these variables that cannot be easily teased apart without complex multivariate analysis. Other low-density communities in this region were found at similar depths, oxygen, and temperature values to the high-density communities.

Table 13. Summary of animal densities and environmental parameters at each dive site.

Dive #	Location	Depth (m)	Porifera/km	Cnidaria/km	Combined/km	Avg Depth (m)	Avg Temp (°C)	Avg O2 (mg/l)
EX1605L3-06	Supply Reef	279-364	95970	1920	97890	298	16.2	6.41
EX1605L1-12	Zealandia	278-655	550	17710	18260	347	13.6	5.69
EX1605L3-03	Maug	321-475	770	9290	10070	345	14.9	6.23
EX1605L1-15	Enrique Guyot	2165-2269	4180	3460	7630	2186	1.9	3.57
EX1605L1-18	Esmeralda Bank	245-530	940	4720	5660	363	9.4	3.45
EX1605L3-01	Farallon de Medinilla 2	486-533	3110	320	3430	509	6.7	2.48
EX1605L1-14	Pigafetta Seamount	1954-2039	130	2940	3070	1983	2.1	3.30
EX1605L3-19	Vogt Guyot	1702-1944	390	2670	3060	1755	2.3	3.03
EX1605L3-02	Pagan	222-396	400	1810	2210	319	13.9	5.68
EX1605L1-02	Santa Rosa South	291-581	190	2010	2200	368	8.5	3.01
EX1605L1-17	Farallon de Medinilla	251-484	0	1470	1470	282	17.0	5.61
EX1605L1-19	Esmeralda Bank Crater	240-248	0	1430	1430	244	16.1	5.24
EX1605L1-01	Santa Rosa North	314-619	220	910	1130	414	8.3	3.09
EX1605L3-07	Chamorro Seamount	859-965	30	920	950	873	4.6	1.85
EX1605L3-15	Explorer Ridge Shallow	1605-1904	60	750	810	1677	2.5	2.90
EX1605L1-16	Del Cano Guyot	1797-1928	490	40	530	1868	2.1	3.33
EX1605L1-08	Northwest Guam Seamount	1159-1343	160	270	430	1234	3.5	2.71
EX1605L3-22	Romeo and Juliet- B29 Bomber	367-374	30	390	420	**	10.2	4.46
EX1605L3-17	Fryer Guyot	1925-2127	90	270	360	2000	2.1	3.23
EX1605L1-13	Kunanaf Hulo Mud Volcano	3673-3702	150	30	180	3680	1.5	4.48
EX1605L3-08	Eifuku Seamount	312-502	40	140	180	453	11.5	5.47
EX1605L3-20	Subducting Guyot 2	4014-4427	180	10	180	4230	1.5	4.60
EX1605L1-06	Fina Nagu C	2524-2752	40	120	160	2614	1.7	3.86
EX1605L3-11	Northern Forearc Ridge	4206-4229	150	0	150	4209	1.5	4.56
EX1605L1-05	Fina Nagu D	2659-2973	70	50	120	2820	1.7	3.93
EX1605L1-04	"Enigma Seamount"	3636-3782	30	70	110	3691	1.5	4.38
EX1605L1-03	"Sirena Canyon"	4849-4964	80	0	80	4884	1.5	4.83
EX1605L3-14	Explorer Ridge Deep	2213-2594	40	20	60	2427	1.8	3.57
EX1605L1-07	Fina Nagu A	2291-2369	10	40	50	2313	2.0	3.62
EX1605L3-13	Twin Peaks	4798-4835	50	0	50	4811	1.5	4.84
EX1605L3-10	Stegasaurus Ridge	3083-3201	40	0	40	3097	1.5	4.18
EX1605L1-11	Hydrothermal Vent	3291-3294	10	0	20	3292	1.7	4.05
EX1605L3-12	Unnamed Forearc Seamount	3296-3318	20	0	20	3306	1.6	4.07
EX1605L3-18	Petite-spot Volcano	5561-5686	20	0	20	5612	1.6	4.94
EX1605L3-05	Ahyi Seamount	270-329	0	10	10	285	16.7	6.46
EX1605L1-10	Potential New Vent Field 1	3864-3868	0	0	0	3866	1.6	4.26
EX1605L3-04	Hadal Ridge	5894-5894	0	0	0	5894	1.6	4.94
EX1605L3-21	Hadal Wall	5816-5816	0	0	0	5816	1.6	4.90
EX1605L3-09	Daikoku Seamount	N/A	0	0	0	N/A	N/A	N/A
EX1605L3-16	Subducting Guyot 1	N/A	0	0	0	N/A	N/A	N/A
EX1605L1-09	Young Lava Flows	N/A	0	0	0	N/A	N/A	N/A

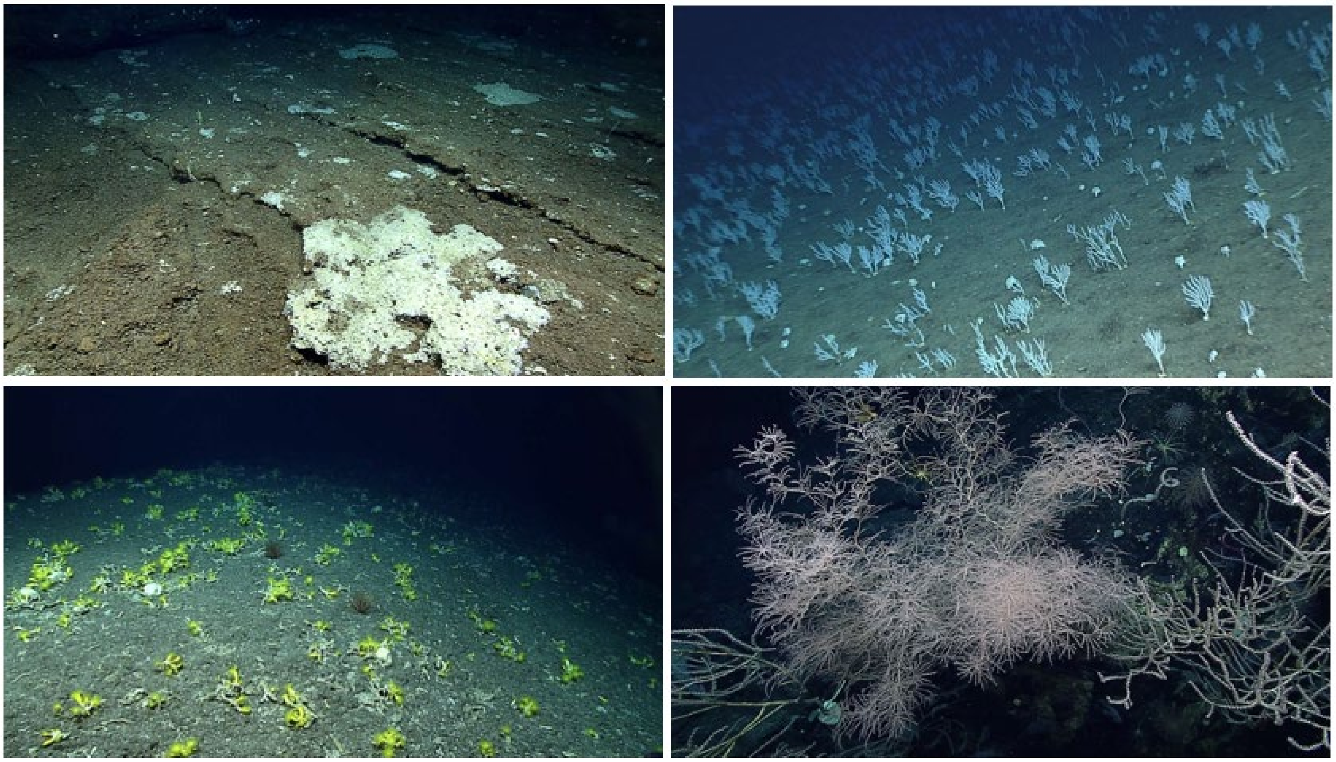

Figure 27. Different types of high-density communities of deep-sea corals sponges.

Furthermore, data acquired from other CAPSTONE regions indicate that DO values can vary considerably within a single community and are therefore not good predictors of the presence of high densities. A recurring theme among the high-density communities in all Pacific regions is that only a small set of taxa accounted for most of the animals seen during the dive. For most of the high-density sites, over 90% of the animal counts were represented by10 or fewer taxa (Fig. 28). Although *P. militaris* was dominant on Vogt Guyot, the relative abundance of other members of the community was somewhat higher compared to the other high-density dives. The top 10 most abundant taxa only accounted for 83.9% of the corals and sponges counted. There are numerous potential factors that could account for the typical high relative abundance of just a few community members including reproductive mode (brooders vs. spawners), pheromone-induced settlement patterns, pioneer species, and the age of the communities. Currently, we are simply documenting this phenomenon and hoping it will lead to sound follow up studies of deep-sea communities to improve our understanding as to why this occurs.

Figure 28. The percentage of total counts for the 10 most numerous taxa of corals and sponges observed at high-density sites found in the Marianas region.

Ridge features were confirmed as sites of large-scale, high-density coral and sponge communities in the Marianas region. Two of the 8 ridge dives conducted were classified as having high-density communities.The western ridge of Vogt Guyot (EX1605L3-19) was primarily dominated by *Pleurogorgia militaris* along with smaller contributions of other chrysogorgiids, isidids, primnoids, antipatharians, and demosponges. The south ridge of Santa Rosa Reef (EX1605L1-02) was the shallowest ridge surveyed at 580 m to 280 m. This location exhibited a moderate-density coral and sponge community. As the dive progressed to the top of the guyot, the coral community shifted from a majority of primnoids corals to a community with a higher contribution by isidids and small contributions of *Paragorgia* sp. and *Pleurocorallium* sp.

The surveys also revealed that the presence of a ridge does not guarantee the presence of a high-density community since other factors such as substrate consolidation and depth are clearly important. A variety of ridge features were surveyed over a broad range of depths, geologic features, and environmental conditions (Table 13). For example, dive EX1605L3-14 surveyed a low-density community on the deeper portion of Explorer Ridge where sediment and cobbles were the most common of the primary substrates. Additionally, three of the ridge dives were carried out at depths below 3,000 m where high-density communities have not yet been observed. A couple of the features with very sparse benthic animals were extremely young lava flows in the volcanically active areas of the back-arc spreading center. It is likely these features had not existed long enough to allow substantial coral and sponge recruitment to occur.

Fifteen of the dive sites showed at least some degree of manganese coating on the substrate. Mn crusts found in this region had varying thickness depending on the age and depth of the geologic feature. The shallowest dives where Mn crust occurred were EX1605L1-02 and EX1605L1-12. These two dives only exhibited a thin veneer of Mn crust on the deeper ends of the depth range between 500 and 600 meters.

Decades ago, Mn crusts were thought to be unsuitable habitats for benthic animals because of their potential toxicity (i.e., copper and arsenic). We now know that this concern was unfounded and very dense communities exist on Mn crusts across the Pacific. In this region, some dives with Mn-crusted substrates had high animal densities such as EX1605L3-19, EX1605L1-14, and EX1605L1-15. Other Mn-coated environments such as Sirena Canyon in the Marianas Trench (EX1605L1-03) or Fina Nagu Caldera A (EX1605L1-07) had extremely sparse coral/sponge communities, presumably due to depth and degree of nearby volcanic activity. Clearly, high-density communities can form on Mn crusts as long as the other requirements to sustain life are met (i.e., optimal depth, oxygen, temperature, and current velocity).

Consistent with findings from other regions, core rock type (i.e., basalt or limestone) does not appear to be a predictor of community density since both low- and high-density communities have been found on both limestone and manganese-crusted basalt bedrock. Substrate consolidation does appear to be an important factor for deep-sea corals and sponges since, similar to other regions, the majority of these animals recorded during the dives in this region were observed attached to bedrock (Table 14). This makes intuitive sense since sessile animals attached to unconsolidated substrates can be toppled during high current flow and subsequently break or die if feeding is compromised.

Table 14. Summary of contact or attachment substrate for different types of corals and sponges.

Phylum	Class	Order	Bedrock	Boulder	Cobble	Pebble	Sediment	Biological
Cnidaria	**Anthozoa**	Alcyonacea	96.3%	3.0%	0.5%	0.0%	0.0%	0.2%
		Antipatharia	93.3%	3.4%	1.2%	0.0%	2.0%	0.0%
		Pennatulacea	2.9%	0.3%	0.3%	0.0%	96.5%	0.0%
		Scleractinia	96.4%	1.2%	1.4%	0.8%	0.1%	0.1%
		Zoantharia	33.3%	0.0%	0.0%	0.0%	0.0%	66.7%
		Unidentified	40.3%	47.6%	7.7%	0.0%	0.0%	4.4%
	Hydrozoa	Anthoathecata	72.1%	9.1%	18.8%	0.0%	0.0%	0.0%
		Leptothecata	64.8%	35.2%	0.0%	0.0%	0.0%	0.0%
Cnidaria Total			**89.9%**	**4.1%**	**4.3%**	**0.2%**	**1.4%**	**0.2%**
Porifera	**Demospongiae**	Haplosclerida	50.0%	0.0%	50.0%	0.0%	0.0%	0.0%
		Poecilosclerida	52.8%	30.1%	13.9%	0.0%	0.3%	2.8%
		Suberitida	57.5%	42.5%	0.0%	0.0%	0.0%	0.0%
		Tetractinellida	89.9%	10.1%	0.0%	0.0%	0.0%	0.0%
		Unidentified	95.1%	4.9%	0.0%	0.0%	0.0%	0.0%
	Hexactinellida	Amphidiscosida	79.2%	9.2%	1.5%	0.8%	8.3%	1.1%
		Hexasterophora incertae sedis	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Lyssacinosida	62.4%	2.6%	2.0%	0.2%	32.4%	0.4%
		Sceptrulophora	86.7%	5.7%	2.4%	0.0%	0.0%	5.2%
		Unidentified	90.0%	3.9%	2.5%	0.4%	0.0%	3.2%
	Unidentified	Unidentified	77.8%	13.0%	3.7%	0.9%	2.8%	1.9%
Porifera Total			**94.0%**	**5.3%**	**0.2%**	**0.0%**	**0.3%**	**0.2%**
Grand Total			**92.3%**	**4.8%**	**1.8%**	**0.1%**	**0.8%**	**0.2%**

Unlike the Wake and Johnston Atoll regions, less than half (17) of the 41 dives conducted in the Marianas region were within the MTMNM boundaries. This is due in part to the high priority placed on geological objectives outside of the monument that are not covered in this report. However, some dives with biological objectives were conducted outside of the monument, because the boundaries of the monument were designed to focus more on the trench and and hydrothermal vent sites than on biological resources.

Pie charts show the relative abundances of various groups of corals and sponges (Fig. 29). Detailed tables providing the counts for corals, sponges, and their associates for each species or lowest possible identification can be found in the regional report. A total of 303 taxa of corals, sponges, and their associates were observed in the Marianas region, which included 3 annelids, 33 arthropods, 1 bryozoan, 3 chordates (2 fish and 1 tunicate), 149 cnidarians, 4 ctenophores, 34 echinoderms, 7 mollusks, 68 sponges, and 1 unidentified phylum. Alcyonaceans were the most abundant order of cnidarians, representing 55% of all the structure-forming corals counted (Fig. 28). Scleractinia and Anthoathecata (structure-forming coral-like hydrozoans) were the other two well-represented orders of cnidarians which together accounted for just under 40% of the counts. Within the Alcyonacea, 15 different families of soft fans and mushroom corals were present with the most abundant being Parisididae (33%). However, this number of counts came primarily from a huge bed encountered on a single dive location. Chrysogorgiidae and Isididae were the next two most abundant families in the Marianas region, each accounting for roughly 13% of the total alcyonacean abundance. Another 27% of the alcyonacean counts came from four families: Plexauridae, Primnoidae, Gorgoniidae, and Acanthogorgiidae. The vast majority of demosponges observed during the dives could not be identified even to order.

Sceptrulophorans were the most abundant glass sponges followed by amphidiscosidans and lyssacinosidans.

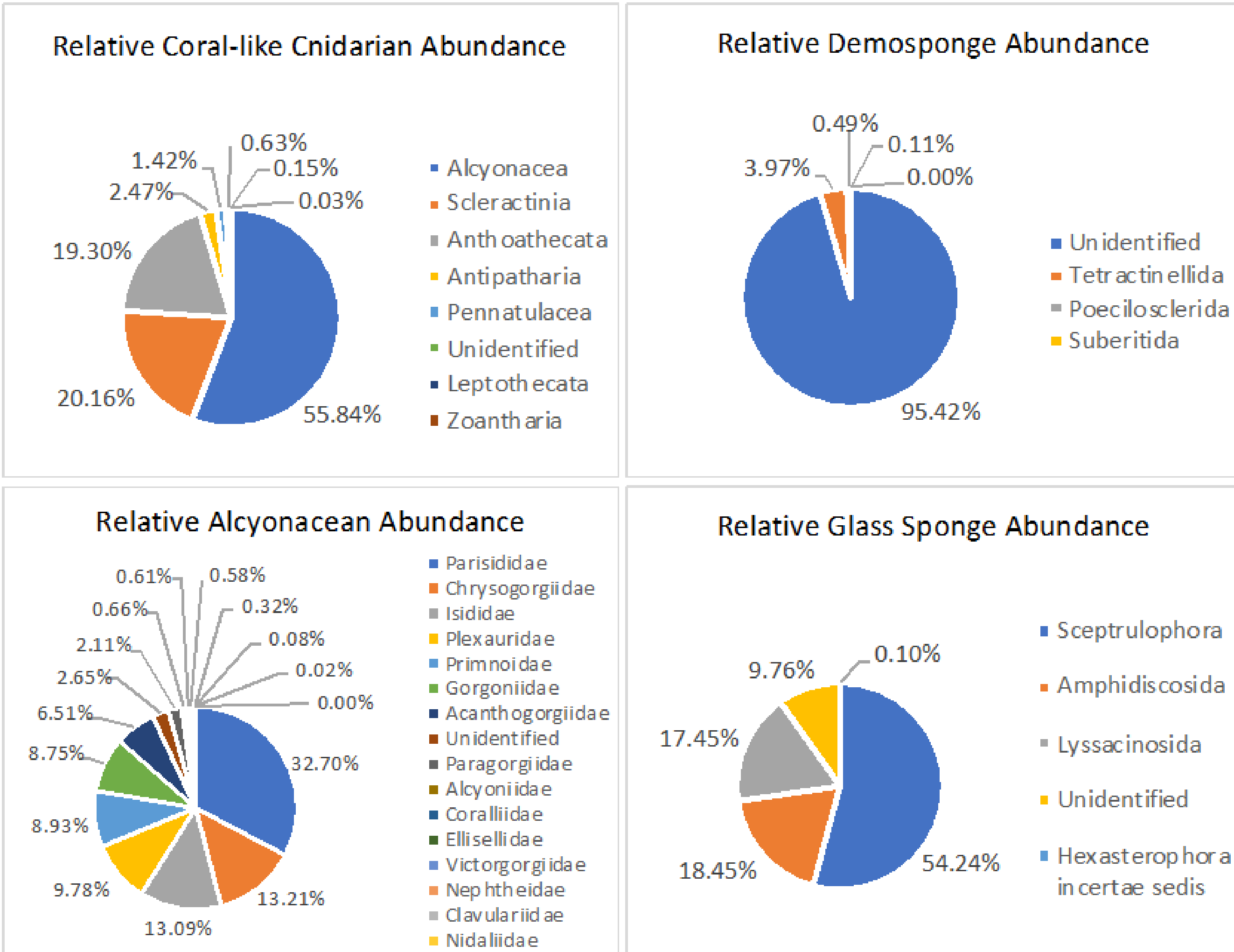

Figure 29. Relative abundance of observed corals and structure-forming hydrozoans (upper left), alcyonaceans (lower left), demosponges (upper right), and glass sponges (Hexactinellida, lower right).

There were 46,071 corals counted in this region. Octocorals were the most plentiful group (26,668) due to the presence of numerous species and the relatively high abundance of such taxa as *Parasis* sp., members of the isidid subfamily Keratoisidinae, the gorgoniid *Eunicella* sp., plexaurids, and *Pleurogorgia* sp. Hexacorals were the second most abundant group (10,439) with the scleractinian *Dendrophyllia* sp. being overwhelmingly the most numerous at over 8,400 counts. Hydrozoans came in third at 8,964 counts, most of which were stylasterids.

Demosponges were by far the most numerous of the sponges observed with 64,619 counted and followed distantly by glass sponges (2,889). Over 60,000 of the demosponges observed could not be identified further; the genus *Poecillastra* was one of the few identified due to its distinctive ribbonlike shape. The most numerous glass sponge was *Psilocalyx wilsoni*, perhaps more reflective of the fact that many of the dives in this region were relatively shallow.

Echinoderms were the most numerous associate fauna encountered, primarily ophiuroids. Mollusks were the next most numerous associate phylum, but this was entirely due to the observation of a large number of vermetids populating *Spongosorites siliquaria*, a demosponge in the family Halichondriidae, all but one during a single dive. Arthropods were the third most numerous group; however, perhaps due to the number of shallower dives conducted in this region, far fewer squat lobsters were observed.

As noted for other regions, many unusual animals were recorded on video that are likely new species; however, new descriptions of species almost always require examination of collected specimens. At this point, very few of the collected specimens have been accessed by taxonomic specialists so it will likely take much more time to determine exactly how many new species were found around the Marianas Archipelago and in MTMNM. Ninety-one specimens of corals, sponges, and associates were collected from the Marianas region, mostly because they were either potential new species or were needed to confirm they were a new record for this region. To this date, two species of primnoid corals have been described from collections in the Marianas region: *Calyptrophora distolos* and *Macroprimnoa ornata* (Cairns 2018). Other noteworthy specimens that are also likely to be new species include a species of *Relicanthus*, an unidentified plexaurid, remarkable lyrate carnivorous sponges in the genus *Chondrocladia*, an unidentified species in the genus *Hyalonema*, several euplectellid glass sponges in the genera *Caulophacus*, *Hyalostylus*, and *Placopegma*. Two examples of these are shown in Figure 30. These are a few of what are likely to be many more as these animals are examined during the next few years.

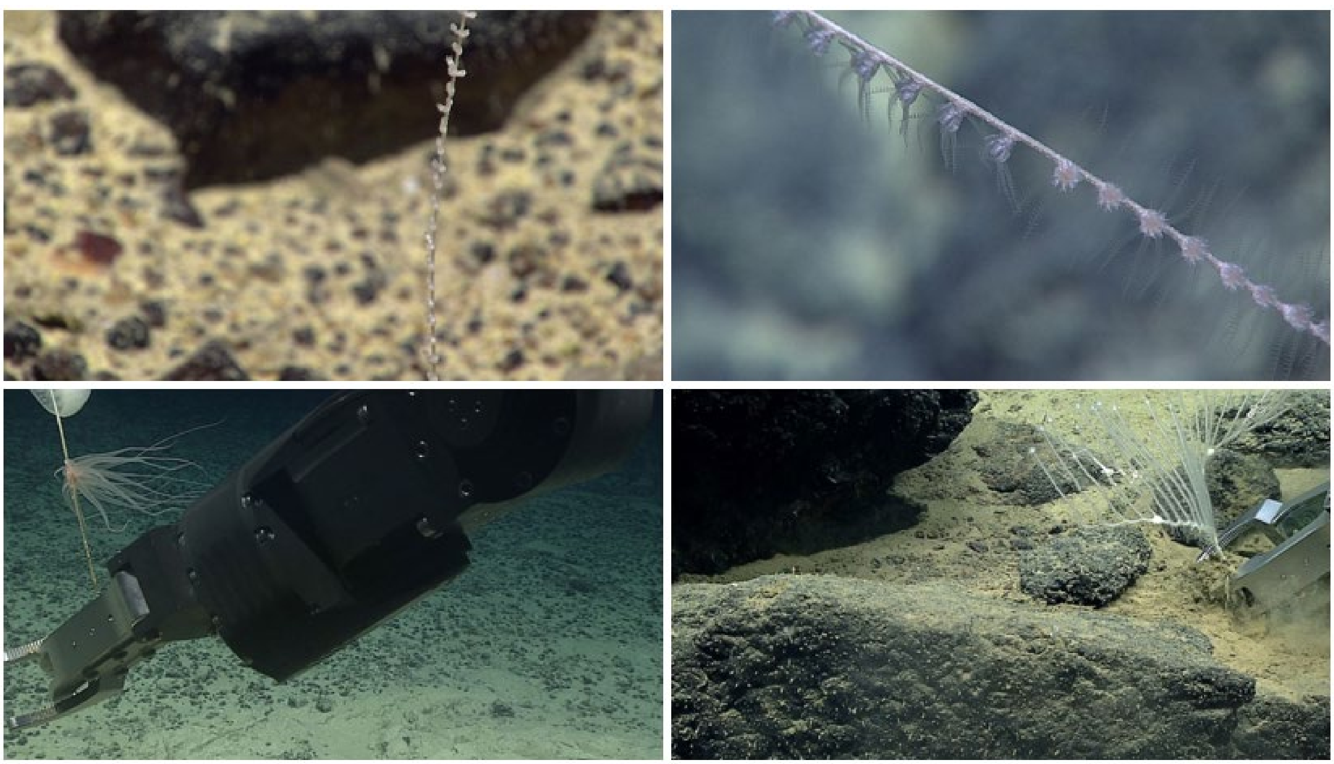

Figure 30. Newly described species of primnoid corals from the Marianas region (*Calyptrophora distolos*, upper left and *Macroprimnoa ornata*, upper right), and potential new species of *Relicanthus* (lower left) and the carnivorous sponge in the genus *Chondrocladia* (lower right).

Phoenix Islands and Tokelau Region Summary

(Excerpted from "A Report to the NOAA Deep-Sea Coral Research and Technology Program April 30, 2019. A Characterization of the Coral and Sponge Communities in the Phoenix Islands & Tokelau Region (Tokelau Seamounts, Howland-Baker Islands Unit of the Pacific Remote Islands Marine National Monument, and Phoenix Islands Protected Area) from *Okeanos Explorer* Surveys Conducted January 31–March 28, 2017).

For this and other regional reports, high-density communities are defined as having at least 3,000 combined coral and sponge counts per kilometer, and very high-density communities have over 10,000 counts per kilometer. Moderate-density communities are defined as those with 1,000–2,999 combined counts per kilometer, low-density communities are those with less than 1,000 combined counts per kilometer. Using these definitions, high-density communities were found at 6 of the 18 dive sites (Table 15). Combined coral and sponge counts at these sites ranged from 3,510 to 9,310 individuals per km, with the highest at Te Kaitira, an unnamed seamount in PIPA. Three other high-density communities were found in PIPA, and only one was found in the Howland-Baker Unit of PRIMNM on Titov seamount. This was the only high-density community found in U.S. waters in this region.

Table 15. Summary of animal densities and environmental parameters at each dive site.

Dive #	Location	Depth (m)	Porifera/km	Cnidaria/km	Combined/km	Avg Depth (m)	Avg Temp (°C)	Avg O2 (mg/l)
EX1703-18	Te Kaitira - Unnamed Seamount (Phoenix Islands Protected Area)	1774-2106	3160	6150	9310	1886	2.4	3.71
EX1703-15	Unnamed Seamount (Phoenix Islands Protected Area)	977-1326	440	5210	5650	1110	4.1	2.79
EX1703-13	Titov Seamount	1138-1228	190	5240	5430	1151	4.1	2.64
EX1703-14	Unnamed Seamount (Winslow Reef Complex PIPA)	1301-1532	4260	580	4840	1395	3.4	3.06
EX1703-17	Unnamed Seamount (North of Carondelet Reef)	463-752	2050	2340	4390	586	7.4	3.37
EX1703-19	Ufiata Seamount	740-1000	3070	440	3510	772	5.9	3.44
EX1703-03	Carondelet Reef	1601-1843	240	2680	2920	1740	2.5	3.68
EX1703-08	Baker Island	423-727	920	1140	2050	497	8.1	2.46
EX1703-05	Polo	1830-2133	230	1440	1670	1918	2.5	3.50
EX1703-10	Howland Island	353-589	140	1410	1550	429	9.3	2.32
EX1703-04	Unnamed Seamount (Athena)	1034-1228	40	1130	1170	1111	4.1	2.98
EX1703-06	Unnamed Seamount (Winslow Reef Complex)	1367-1562	40	1110	1160	1445	3.2	3.13
EX1703-02	Pao Pao	266-537	80	970	1050	382	10.7	2.80
EX1703-07	Titov	1692-1879	190	520	710	1735	2.6	3.07
EX1703-11	Howland Island	2084-2228	230	340	580	2176	2.1	3.44
EX1703-09	Howland Island	2214-2415	200	340	540	2276	2.0	3.57
EX1703-12	Baker Island	1494-1857	40	230	270	1701	2.6	3.08
EX1703-16	Hadal Trough ("Kinono")	5769-5855	30	10	50	5802	1.4	5.56

The depth range for these communities was 463–2,106 m; 5 out of the 6 were found below 740 m. However, this is likely a sampling artifact since deeper dive sites were prioritized over shallower ones. The one shallower high-density community (Dive 17) was found near the summit of an unnamed seamount where there were substantial numbers of primnoids and sponges. A large white paragorgiid octocoral (possibly *Sibogagorgia* sp.) was seen with unusual blue or black ophiuroids, possibly in the family Euryalidae. A few large (> 1.5 m tall) gold coral (*Kulamanamana haumeaae*) were also encountered and one was sampled at 488 m (D2_DIVE17_SPEC01BIO). The other five deeper high-density communities each had a unique species composition (Fig. 31). Some species were only found at one location while others were present in many dives. Two of the 6 were found to be dominated by primnoids, 2 were dominated by plexaurids, and the other 2 were dominated by demosponges. These communities were also characterized by having a large number of counts of a relatively few number of species, a recurring theme among high-density communities across the Pacific. The10 most abundant animal taxa in each of these high-density communities account for 85–95% of the total animal abundance.

Figure 31. Different types of high-density communities of deep-sea corals sponges were encountered at a number of the dive sites, including ones dominated by large unidentified primnoids (upper left), yellow plexaurids (upper right), *Paracalyptrophora hawaiiensis* (lower left), and sponges (lower right).

Eight of the dives conducted in this region during EX1703 took place on ridge topography. Dives 5, 7, 9, 11, and 12 surveyed ridge habitats associated with islands or tablemounts. Dives 2, 17, and 19 surveyed along the flank or summit of seamounts that had rift zone ridges. The ridge surveys spanned a variety of depths, environmental conditions, and substrate types. Ridges were confirmed as sites for high-density communities during Dive 17, which was relatively shallow at 463–752 m and had a carbonate substrate and Dive 19 that was deeper at 740–1,000 m with a substrate composed primarily of bedrock and boulders. Surprisingly, all other surveyed ridges had sparse to moderate numbers of corals and sponges despite being within a suitable depth range and having a suitable substrate for high-density communities. Only Dive 12 found a relatively large proportion of unconsolidated cobbles and sediment substrate present. Clearly other factors besides the presence of a ridge contribute to the formation of large-scale high-density communities. More ridges will need to be surveyed to help distinguish the patterns between high- and low-density environments. Future research can investigate other factors such as food availability and current velocity on these ridges.

The presence of Mn crusts was still noted during the annotations even though this region is located outside of the Prime Crust Zone. Fourteen of the 18 dive sites had Mn crust substrates with varying thicknesses, which was assumed to be a result of the substrate age and depth. Dive 19 on Ufiata Seamount exhibited a transition from Mn crust basalt bedrock and boulders to carbonate at approximately 1,000 m that continued up to the 740 m endpoint of the dive. The four dive sites where Mn crusts were not observed were all shallow, depths at which Mn crusts have never been recorded in the Pacific (2, 8, 10, 17 m).

Table 16 provides a summary of the attachment substrates for the corals and sponges observed during the dives. As with other regions, substrate consolidation does appear to be an important factor for the development of deep-sea coral and sponge communities since the majority of these animals were observed attached to bedrock. Sea pens (Pennatulacea) are one of the only octocoral groups that are adapted to sediment substrates. Six colonies of the hydrozoan *Solanderia* sp. were recorded in this region, four of which appeared to be attached to sediment. Although many amphidiscosidan sponges are observed on hard substrates, their thread-like basalia (basal spicules) allow for a small number of species to also secure themselves to sediments.

Detailed tables providing the counts for corals, sponges, and their associates for each species or lowest possible identification can be found in the regional report. Alcyonaceans were the most abundant order of corals observed and represented 83% of all counted corals. Antipatharians, scleractinians, and pennatulaceans were the next most abundant orders at 10%, 5%, and 2%, respectively. Very few zoantharians or hydrozoan corals were present. Amongst the families of alcyonaceans, primnoids, plexaurids, and chrysogorgiids were the most abundant at 36%, 28%, and 17%, respectively. Isidids, paragorgiids, and coralliids were also present but at much lower abundance, together contributing to approximately 16% of the counts.

Unlike glass sponges, most demosponges were not identifiable from the video. Poecilosclerida and Tetractinellida were the orders that were somewhat recognizable. Lyssacinosidans, in the families Euplectellidae, Rossellidae, and Aulocalycidae, were the most abundant glass sponges by far. One hundred and twenty-eight different taxa of coral, 51 different types of sponges, and 87 different types of associates were documented in the Tokelau region, the latter including 2 annelids, 37 arthropods, 2 ctenophores, 36 echinoderms, 6 mollusks, and a nemertea. Antipatharians were the most numerous hexacorals, particularly *Stichopathes* sp. and *Trissopathes* sp. although many different species were documented. Scleractinians were much less abundant with the exception of *Enallopsammia rostrata*, a well-known bedding species found in shallow to intermediate depths. A large number of different octocorals were also documented, most noteworthy of which were unidentified plexaurids, unidentified primnoids, unidentified species of primnoid in the genus *Narella*, an identified primnoid (*Paracalyptrophora hawaiiensis*), the chrysogorgiid *Pleurogorgia militaris* and unidentified species in the subfamily Keratoisidinae. The number of *P. hawaiiensis* recorded is particularly interesting since this species was seldom recorded elsewhere in the Pacific. More demosponges than glass sponges were observed in this region, most were unidentified demosponges and 38% were in the order Poecilosclerida. Euplectellid sponges in the order Lyssacinosida accounted for 58% of the glass sponges recorded, the most common were unidentified Corbitellinae, *Walteria flemmingi,* and unidentified species of *Walteria*.

Table 16. Summary of contact or attachment substrate for different types of corals and sponges.

Phylum	Class	Order	Bedrock	Boulder	Cobble	Pebble	Sediment	Biological
Cnidaria	**Anthozoa**	Alcyonacea	84.4%	15.1%	0.1%	0.0%	0.1%	0.3%
		Antipatharia	96.7%	2.7%	0.4%	0.1%	0.1%	0.1%
		Pennatulacea	2.3%	0.9%	0.0%	0.0%	96.9%	0.0%
		Scleractinia	95.3%	1.5%	0.0%	0.0%	0.4%	2.8%
		Zoantharia	84.6%	0.0%	0.0%	0.0%	0.0%	15.4%
		Unidentified	51.4%	48.6%	0.0%	0.0%	0.0%	0.0%
	Hydrozoa	Anthoathecata	0.0%	33.3%	0.0%	0.0%	66.7%	0.0%
		Leptothecata	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cnidaria Total			**84.1%**	**13.1%**	**0.1%**	**0.0%**	**2.2%**	**0.4%**
Porifera	**Demospongiae**	Poecilosclerida	89.2%	10.7%	0.1%	0.0%	0.0%	0.0%
		Tetractinellida	89.2%	7.6%	0.4%	0.0%	0.0%	2.8%
		Polymastiida	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Unidentified	95.6%	3.8%	0.1%	0.0%	0.3%	0.2%
	Hexactinellida	Amphidiscosida	81.3%	6.6%	0.0%	0.0%	2.7%	9.3%
		Hexasterophora incertae sedis	74.5%	25.5%	0.0%	0.0%	0.0%	0.0%
		Lyssacinosida	81.9%	16.7%	0.2%	0.0%	0.3%	0.9%
		Sceptrulophora	92.7%	6.9%	0.0%	0.0%	0.0%	0.4%
		Unidentified	88.0%	10.2%	0.0%	0.0%	0.0%	1.8%
	Unidentified	Unidentified	94.2%	1.5%	1.0%	0.0%	0.0%	3.4%
Porifera Total			**89.0%**	**9.8%**	**0.2%**	**0.0%**	**0.2%**	**0.8%**
Grand Total			**85.7%**	**12.0%**	**0.1%**	**0.0%**	**1.6%**	**0.6%**

Echinoderms were the most abundant associates; the majority were documented on corals. Similar to other regions, ophiuroids and comatulid crinoids were by far the most abundant of these, with the former known to have specific, apparently commensal relationships with chrysogorgiids, plexaurids, and primnoids. Arthropods were the next most abundant associate group; poecilasmatid barnacles had the most counts. There were many types of decapods documented as well, but each in relatively low numbers.

A region-specific objective, to survey for relatively shallow precious corals, was also addressed on four dives. On Dive 17, a high-density coral community was observed on an unnamed seamount north of Cardonelet Reef. During this dive, the precious gold coral, *Kulamanamana haumeaae,* and its isidid host *Orstomisis* sp., were found interspersed within the beds of *Paracalyptrophora hawaiiensis*. The other three precious coral depth dives were on the flanks of Howland and Baker Islands and Pao Pao seamount (Dives 10, 8, and 2, respectively). Moderate communities of corals and sponges were observed at these locations that consisted primarily of primnoids, antipatharians, and demosponges. Similar to *K. haumeaae*, precious red or pink corals in the family Coralliidae were relatively rare at these sites yet, these records represent the first documentation of commercially valuable coral in the Tokelau region.

As with other regions, many unusual animals were recorded on video that are likely new species; however, almost all new descriptions of species require careful examination of collected specimens. At this point, it is also difficult to determine the number of new species collected during the dives since many have not been carefully examined by taxonomic specialists. Eighty- four specimens of corals, sponges, and associate animals were collected in the Tokelau region.

With the exception of the associates, all primary biological specimens were collected because they were either potential new species or were needed to confirm a new record for this region. To this date, three new species of primnoid coral have been described and published by Cairns (2018) for this region: *Narella fordi*, *Callogorgia cracentis*, and *Calyptrophora pourtalesi*. Example images of two of these new species are shown in Figure 32.

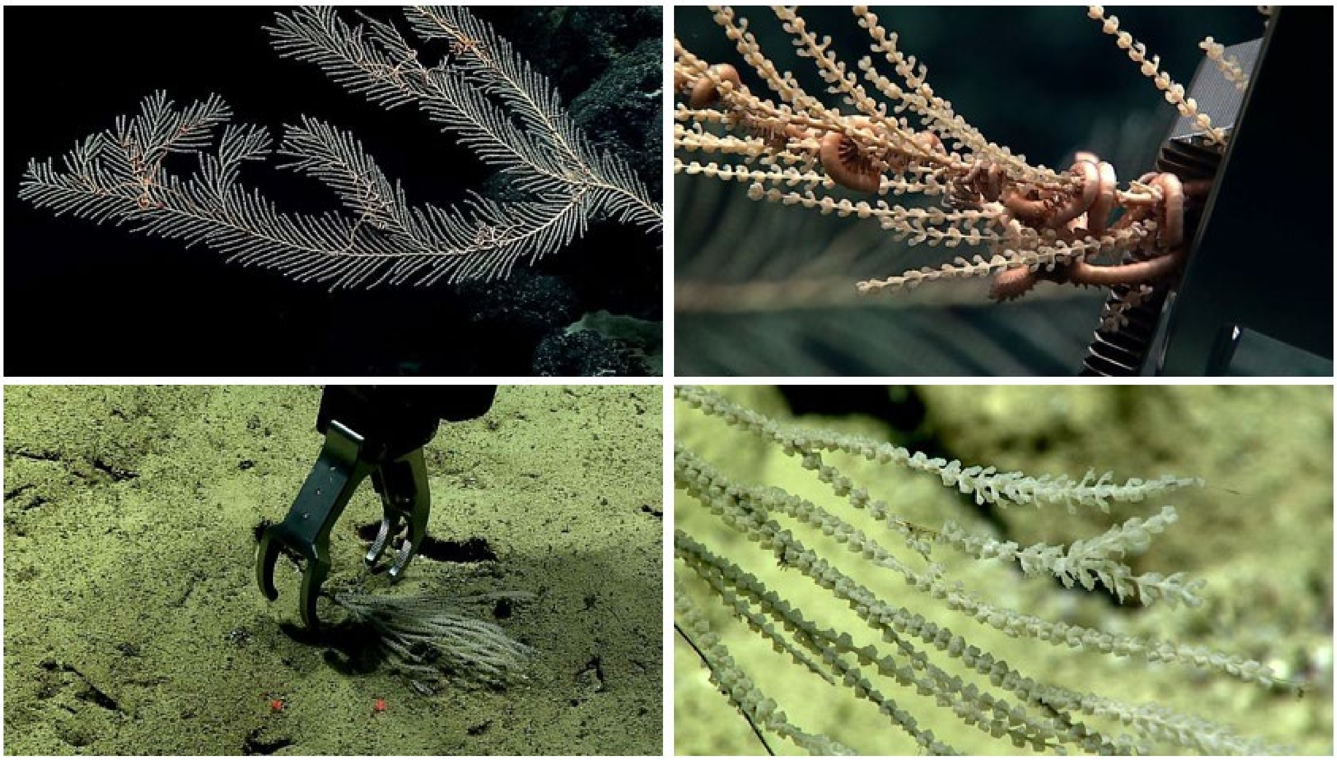

Figure 32. Newly described primnoid species, *Callogorgia cracentis* (upper) and *Calyptrophora pourtalesi* (lower), from the Howland-Baker unit of PRIMNM.

Line Islands Regional Summary

(Excerpted from "A Report to the NOAA Deep-Sea Coral Research and Technology Program May 1, 2019. A Characterization of the Coral and Sponge Communities in the Jarvis, Palmyra, and Kingman Reef Units of the Pacific Remote Islands Marine National Monument from *Okeanos Explorer* Surveys Between January 24 and May 14, 2017")

High-density communities are defined as having at least 3,000 combined coral and sponge counts per kilometer, very high-density communities have over 10,000 counts per kilometer. Moderate-density communities are defined as those with 1,000–2,999 combined counts per kilometer, and low-density communities are those with less than 1,000 combined per kilometer. Using these definitions, 3 of the 9 sites surveyed in this region can be characterized as having high-density communities. Each high-density community was found in a distinct habitat which included an island ridge (EX1705-05), a cone on the summit of a guyot (EX1705-07), and a conical feature along the eastern slope of Kingman Reef (EX1705-11). The 3 communities were dominated more by corals (3,490–4,580 individuals/km) than sponges (50–680 individuals/km, Table 17).

Table 17. Summary of animal densities and environmental parameters at each dive site.

Dive #	Location	Depth (m)	Porifera/km	Cnidaria/km	Combined/km	Avg Depth (m)	Avg Temp (°C)	Avg O2 (mg/l)
EX1705-11	Kingman Cone	1007-1031	50	4580	4630	1020	4.5	1.64
EX1705-07	Whaley Seamount	859-1105	680	3490	4170	922	5.1	2.53
EX1705-05	Jarvis Island	350-821	490	3580	4070	495	8.9	2.43
EX1705-04	Kahalewai	1536-1700	30	1000	1030	1673	2.7	3.20
EX1705-10	South Palmyra Slope	298-493	20	690	710	387	9.1	0.79
EX1705-09	West Palmyra Seamount	2087-2172	50	430	480	2127	2.2	3.19
EX1705-12	Kingman Deep	1818-2255	60	160	210	2017	2.3	3.06
EX1705-06	Keli'ihananui	1766-1918	20	170	190	1842	2.4	3.20
EX1705-08	Clipperton Fracture Zone	4368-4571	10	70	80	4491	1.3	5.31

These communities were found in both the Kingman-Palmyra and Jarvis Island Units of PRIMNM and were among the shallowest and warmest surveyed in the region. The depths ranged from 350 m at Jarvis Island to 1,105 m at Whaley Seamount. The average temperatures were relatively high, ranging from 4.5 °C to 8.9 °C, while the average dissolved oxygen ranged from 1.64 mg/L to 2.53 mg/L.

Only one other dive (EX1705-10) along the south Palmyra slope explored depths shallower than 1,000 m, where a low-density community (710 individuals/km) was found. This site also has the lowest average dissolved oxygen level (0.79 mg/L) found in the region. A moderate-density community on a ridge of Kahalewai seamount was observed in somewhat deeper (1,536 to 1,700 m) and cooler (2.7 °C) waters. Only low-density communities were found on all of the other dives that were deeper than 1,750 m in this region.

Similar to high-density communities found elsewhere, the 10 most abundant taxa at each site accounted for the vast majority of the corals and sponges recorded; however, the community composition varied among sites (Fig. 33). More than 90% of the corals and sponges belonged to 10 or fewer taxa at each dive site, and a single taxon accounted for more than half of the total corals and sponge counts. The highest density community was found at Kingman Cone (EX1705-11) where yellow gorgonian fans in the genus *Acanthogorgia* contributed to over three-quarters of the coral and sponge totals. Other dominant taxa included other gorgonians (i.e., primnoids, plexaurids, isidids, and paragorgiids), black corals, and sea pens; sponges accounted for less than 1% of the individuals in this community. The Whaley Seamount site (EX1705-07) in the Jarvis Island Unit of PRIMNM was dominated by plexaurids and to a lesser extent by demosponges (including Poecilosclerida and geodiids), scleractinians (*Madrepora oculata* and *Enallopsammia rostrata*), and other gorgonians (i.e., primnoids, acanthogorgiids, and gorgoniids). The shallowest community off Jarvis Island (EX1705-05) consisted primarily of a primnoid coral in the genus *Thouarella* and in smaller numbers, stoloniferous octocorals, a plexaurid in the genus *Paracis*, scleractinians, demosponges and glass sponges. Figure 33 provides example images from two of these three communities.

Figure 33. The percentage of total counts for the 10 most numerous taxa of corals and sponges observed at high-density sites found in the Line Islands region.

Rift zone ridges were confirmed as sites of large-scale, high-density coral and sponge communities during the CAPSTONE expedition. However, the surveys also revealed that the presence of a ridge does not guarantee the presence of a high-density community. Of the five ridges surveyed in the Line Islands, only one site along the slope of Jarvis Island (EX1705-05) was found to have this type of community. A moderate-density community was also found on the prominent south-southwest trending ridge extending from the conical Kahalewai Seamount. The other three surveyed ridges supported only sparse coral and sponge communities, indicating other factors such as substrate consolidation and depth may be important. For example, the lowest-density community on an east-northeast trending ridge along the Clipperton Fracture Zone (EX1705-08) was surveyed at an average depth of 4,491 m. The area surveyed was primarily covered with sediment. Both the heavy sedimentation and abyssal depth may have contributed to low coral and sponge densities. Large-scale, high-density coral and sponge communities have not yet been observed on features deeper than 2,800 meters.

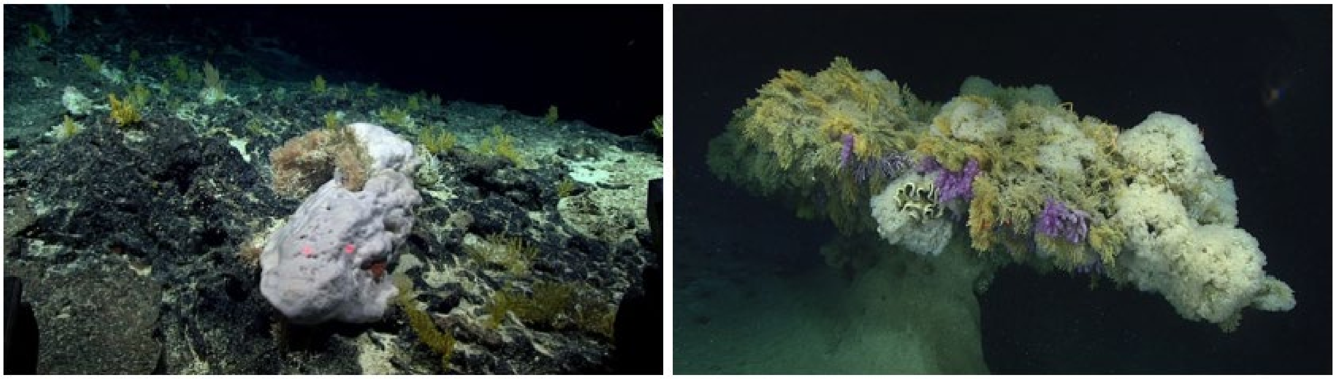

Figure 34. High-density communities seen in the Line Islands region, including one at Whaley Seamount dominated by plexaurids, demosponges, and scleractinians (left) and another at Jarvis Island which included an eroded carbonate structure densely packed corals and sponges (right).

Another possible important environmental factor that was not quantified in these dives is current velocity. Ridge features or rugose surfaces with boulders and ledges tend to locally accelerate currents, which could enhance the flux of dissolved and particulate organic matter to filter-feeding organisms. Higher localized currents could also prevent settling of sediments to preserve exposed hard substrates to which sessile animals can attach.

Four dives (9–12) were conducted in the northern end of this region that lies within the Prime Crust Zone (PCZ); however, the presence of Mn crusts was noted for all 9 dives. Six of the dives took place within the target Mn crust mining depth range between 1,000 and 2,500 m, including three (Dives 9, 11, and 12) in the PCZ. All six sites contained areas where large portions of substrate were coated in Mn crusts. Three dives (6, 7, and 9) were on guyots, which are the types of seamounts likely to be targeted for future mining activities due to their flat tops and old age. The shallow dive off Palmyra Atoll (EX1705-10) was the only site completely devoid of Mn crust material.

Both sparse and dense communities were found on Mn crust substrate and within the optimal mining depth range. Two of the 3 high-density communities (EX1705-07 and EX1705-11) were observed in Mn crust environments while the third site (EX1705-05, shallower than 1,000 m) was noted as having only a thin coating of Mn crust in the deeper portion of the dive. The moderate- and low-density communities were also found in Mn crust habitats. Thick Mn crusts were observed at the site with the lowest density of corals and sponges, but this was also deeper than the target depth for Mn mining and at depths where high-density communities have not been observed.

Substrate consolidation and grain size may play a more important role than Mn coating in the development of large-scale, high-density coral and sponge communities. Dive sites where the habitat was composed of a large proportion of sediment tended to have lower coral and sponge densities. The preference for bedrock and large boulders as contact substrates for most corals and sponges was evident in this region (Table 18) and other locations surveyed during CAPSTONE.

Table 18. Summary of contact or attachment substrate for different types of corals and sponges. List of phylum, class, order, and percent bedrock, boulder, cobble, pebble, or sediment, plus percent biological.

Phylum	Class	Order	Bedrock	Boulder	Cobble	Pebble	Sediment	Biological
Cnidaria	**Anthozoa**	Alcyonacea	80.5%	13.4%	0.2%	0.0%	0.0%	5.9%
		Antipatharia	86.9%	11.5%	0.5%	0.0%	0.0%	1.0%
		Pennatulacea	8.4%	1.5%	0.0%	0.0%	90.1%	0.0%
		Scleractinia	59.3%	11.2%	0.1%	0.0%	0.1%	29.3%
		Zoantharia	25.0%	0.0%	0.0%	0.0%	0.0%	75.0%
		Unidentified	52.2%	47.8%	0.0%	0.0%	0.0%	0.0%
	Hydrozoa	Anthoathecata	7.4%	92.6%	0.0%	0.0%	0.0%	0.0%
		Leptothecata	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%
Cnidaria Total			**75.3%**	**13.1%**	**0.2%**	**0.0%**	**2.9%**	**8.5%**
Porifera	**Demospongiae**	Poecilosclerida	85.9%	13.6%	0.5%	0.0%	0.0%	0.0%
		Tetractinellida	84.8%	11.8%	0.0%	0.0%	0.0%	3.4%
		Unidentified	75.3%	22.9%	0.2%	0.0%	0.0%	1.5%
	Hexactinellida	Amphidiscosida	60.0%	5.0%	5.0%	0.0%	30.0%	0.0%
		Hexasterophora incertae sedis	88.0%	7.2%	0.0%	0.0%	0.0%	4.8%
		Lyssacinosida	89.7%	8.8%	0.0%	0.0%	0.0%	1.5%
		Sceptrulophora	70.7%	7.3%	0.0%	0.0%	0.0%	22.0%
		Unidentified	85.7%	3.6%	3.6%	0.0%	0.0%	7.1%
	Unidentified	Unidentified	48.2%	3.6%	0.0%	0.0%	0.0%	48.2%
Porifera Total			**79.2%**	**14.8%**	**0.4%**	**0.0%**	**0.6%**	**5.1%**
Grand Total			**75.8%**	**13.3%**	**0.2%**	**0.0%**	**2.6%**	**8.1%**

All 9 dives were within the Pacific Remote Islands Marine National Monument (PRIMNM) boundaries; 4 in the Kingman Reef and Palmyra Atoll Unit and 5 in the Jarvis Island Unit. A detailed analysis of the animals recorded within this monument unit is beyond the scope of this report. However, this section does provide some basic summary charts and tables of the corals, sponges, and their associated fauna found in this region. Pie charts show the relative abundances of various groups of corals and sponges (Fig. 34). Detailed tables providing the counts for corals, sponges, and their associates for each species or lowest possible identification are available in the regional report. A total of 185 taxa of corals, sponges, and their associates were identified within the Line Islands, including 89 cnidarians, 35 sponges, 2 annelids, 26 arthropods, 3 fish, 1 ctenophore, 24 echinoderms, and 5 mollusks. Alcyonacea was the most abundant order of corals comprising over 80% of the coral counts. Scleractinia, Pennatulacea, and Antipatharia followed, contributing 12.6%, 3.2%, and 2.3%, respectively. The most abundant alcyonacean family, Primnoidae, accounted for 39% of the community (Fig. 34) and was approximately 30% of all coral counts in this region. This relatively high primnoid abundance was only seen in one other region during CAPSTONE, the Tokelau region, which extends up from the boundary of the American Samoa EEZ through the Tokelau Seamounts to the Howland and Baker Islands Unit of PRIMNM. With the exception of the Wake Island region, this high proportion of primnoids corals in the Line Islands and Tokelau regions was more than double that observed in other regions.

While primnoids were observed at seven dive sites, 85% were recorded during a single dive (EX1705-05); this included 2,177 of the 2,179 *Thouarella* colonies documented in this region. Three families (plexaurids, acanthogorgiids, and primnoids) accounted for more than 82% of the relative abundance of alcyonacean families and each were a dominant family at 1of the 3 high-density sites (Fig. 35). Clearly, the relative abundance of coral families is heavily influenced by the low sample size of dive sites and the communities observed in the high-density beds. Surprisingly, the family Isididae was relatively less abundant than observed in other regions and only contributed to 2.5% of the total alcyonacean counts as compared with 5% in the Tokelau and Wake Island regions and 13–40% in the five other regions.

At all nine dive sites, sponges were less abundant than corals and contributed to only about 12% of the overall coral and sponge counts in the region. More demosponges than glass sponges were observed in this region, but most (50.6%) could not be identified to order (Fig. 35). About one-quarter (26.9%) of the demosponges were assigned to the order Poecilosclerida, which included a small portion identified as carnivorous sponges in family Cladorhizidae. The remaining demosponges (22.5%) were in the order Tetractinellida and included corallistids, geodiids, and vulcanellids. Within the hexactinellid glass sponges, about one-third (34.6%) were in an order of uncertain taxonomic placement (i.e., Hexasterophora incertae sedis), all of which were identified to the genus *Heterorete*. Euplectellid and rossellid sponges (order Lyssacinosida), auloplacids, cribrispongiids, euretids, and farreids (order Sceptrulophora), along with the *Heterorete* sponges, accounted for 80% of the glass sponges observed in this region.

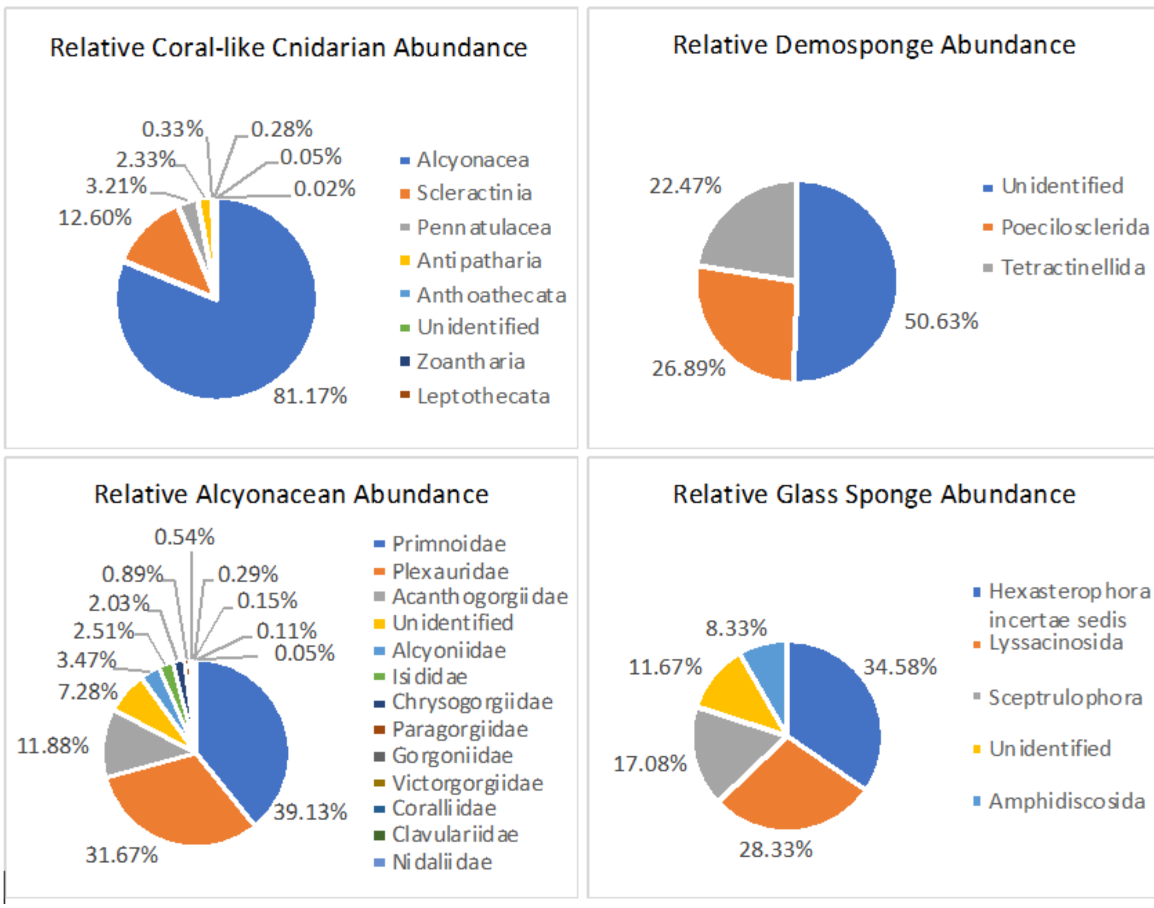

Figure 35. Relative abundance of observed corals and structure-forming hydrozoans (upper left), alcyonaceans (lower left), demosponges (upper right) and glass sponges (Hexactinellida, lower right).

The coral community at Jarvis Island (Dive 5) was primarily composed of primnoid fans in the genus *Thouarella*, stoloniferous octocorals, and plexaurid colonies in the genus *Paracis*. Scleractinians such as *Madrepora oculata* and *Enallopsammia*, tetractinellidan demosponges and glass sponges (notably *Heterorete* sp.) were also minor contributors to the community. Only four gold coral (*Kulamanana* *haumeaae*) colonies were counted on this site, which may be because the dive depth range was at the lower end for this species. The community found in the shallow dive off Palmyra Atoll, while low in density, consisted of the scleractinians, such as *Enallopsammia rostrata*, gorgonian fans (*Narella* sp., *Paracalyptrophora hawaiiensis*, *Acanthogorgia* sp.), the stylasterid *Lepidopora* sp., and black corals (*Hexapathes heterosticha* and *Stichopathes* sp.).

The most common animal phylum to associate with corals and sponges in this region was echinoderms. Similar to other regions, ophiuroids and comatulid crinoids were by far the most abundant constituting 98% of the echinoderm counts in this region. About one-third (35%) of the observations were euryalid ophiuroids wrapped up in the branches of plexaurid colonies. Both ophiuroids and comatulid crinoids showed a strong association with the oculinid, *Madrepora oculata*. With respect to sponges, ophiuroids in the genus *Ophioplinthaca* were found in association with euplectellids in the genus *Bolosoma*. While fewer echinoderms were documented on sponges, this appears related to the low availability of sponges rather than a preference for corals, based on the fact that the same percentage (about 12%) of both corals and sponges had echinoderm associates. Arthropods were the next most abundant associate group with poecilasmatid barnacles showing a strong association for isidid colonies. Amphipods and a variety of decapods were also found to associate with both corals and sponges.

As with other regions, many unusual animals were recorded on video in this region that are likely new species; however, almost all new descriptions of species are based on careful examination of collected specimens. Among animals collected, it is difficult to determine the number of new species since many have not been accessed by taxonomic specialists. With the exception of the associates, almost all of the primary biological specimens were collected because they were either potential new species or were needed to confirm a new record for this region.

There were 35 specimens of corals, sponges, and associates collected in the Line Islands region, most of the targeted specimens were collected on the basis of being a potential new species and/or new record expanding the range of existing species to the Line Islands region. Of particular note are an unidentified species of *Swiftia* (Plexauridae), a demosponge in the family Cladorhizidae, and a glass sponge potentially in the genus *Stereochlamis*. To date, one new species of primnoid coral, *Narella ferula*, has been described and published by Stephen Cairns in 2018 from this region. This specimen was a fortuitous collection during EX1705-11 as the targeted specimen was the rock to which it was attached (Fig. 35). Many other animals recorded on video are also likely new species; they are now known to exist and can be targeted for collection on future cruises.

Figure 36. A new species of primnoid, *Narella ferula*, discovered in the Kingman Reef and Palmyra Atoll unit of PRIMNM. The blue arrow in the left image points to the colony collected.

Project 5. Field and laboratory research to examine the population size-structure, ecology, growth rates, genetics, and distribution of black corals in Hawaii, including the establishment of monitoring sites to sample and study growth and post-harvest recovery rates of SCUBA-accessible black coral populations in the MHI.

Lead Investigators: Anthony Montgomery – Hawaii Institute of Marine Biology – University of Hawaii at Mānoa (amont@hawaii.edu), Robert Toonen – Hawaiʻi Institute of Marine Biology – University of Hawaii at Mānoa (toonen@hawaii.edu)

Collaborators; Zac Forsman – Hawaii Institute of Marine Biology – University of Hawaii at Mānoa (zac@hawaii.edu)

Hawaii is one of only a few places where black coral is harvested for the precious coral jewelry industry. Recent surveys (Montgomery, unpublished data) indicate substantial declines in recruitment and a decrease in larger individuals within the size structure of the black coral population. These observations raise questions about whether fishery regulations need to be redefined in order to maintain sustainable harvests. Lack of information about the basic life history of black coral complicates effective management of the fishery. This project worked to characterize the growth rates and minimum size of reproductive maturity of the 3 commercially valuable Hawaiian black coral species (*Antipathes griggi*, *A. grandis,* and *Myriopathes* cf. *ulex*) and determine whether these parameters vary by depth in order to begin to answer four questions: (1) what is the current population size structure within the Maui black coral beds and how has it changed over time, (2) what are the species and colony densities in the depths of 60–80 m in the Auʻau Channel, Maui, (3) what is the connectivity of *Antipathes griggi* across the Maui beds and at other islands (Hawaiʻi, Oʻahu, Kauaʻi, Northwestern Hawaiian Islands, and Johnston Atoll), and (4) can we predict the impacts of changes to the population through the development of a population model based on demographics and spatial distributions?

Field surveys were conducted using mixed-gas technical diving at depths between 50 and 90 m off Oahu and Maui. Black coral colonies were tagged and measured and re-measured over a three-year period to determine their growth rates. Colonies were sampled to determine their reproductive maturity using standard histological techniques (Wagner et al. 2011a, 2012). This research provided key parameters which are essential to update models that have been used to manage the Hawaiian black coral fishery.

Population variables of recruitment, growth, mortality, fecundity, colony density, colony distribution, and genetics were analyzed together to create a complete picture of the population dynamics of the Hawaiian antipatharians. This research was conducted in collaboration with the research proposal (Wagner – "Field surveys of SCUBA-accessible black coral populations in Hawaii and American Samoa to determine taxonomy and distribution of black corals."). Montgomery and colleagues monitored the population size structure in the Auʻau Channel, Maui, by conducting transects at depths that had not been previously surveyed off Maui (60–80 m) to determine the population connectivity of *Antipathes griggi* across small and large scales and utilized historical and new data to model the population demographics and distribution.

These data include the measurements of individual colonies at similar sites within the Auʻau Channel, using data collected in 1975, 1998, 2004, 2010, and 2018 (Fig. 37). These size class distribution data allowed additional analysis of key demographic characteristics (e.g., survival, mortality, and recruitment). An example of this analysis is shown in Figure 38, which shows the slope of the regression across pre- and post-harvestable size classes approximating the mortality rate per year. This analysis will form the foundation of building a predictive model that can test for changes in the population demographics based on key characteristics such as mortality, growth, and recruitment.

Montgomery and colleagues compiled the existing growth rate data available. These data include 16 colonies measured by R. Grigg at 11 unique time intervals over an approximate 3-year period (Grigg 1976) in addition to 39 colonies measured by A. Montgomery at four unique intervals over approximate 2-year period (Montgomery 2006, Montgomery unpub). These growth data have allowed some exploratory modeling of the growth curve and rates of *A. griggi* (Fig. 39). This exploratory work indicates that the growth rate is relatively linear but has varies over time. Grigg (1976) reported the linear growth rate of *A. griggi* to be 6.42 cm per year. The results of this exploratory model indicate a similar growth rate of 6.61±0.38 cm per year. While these results are similar to previously reported values, the modeling will incorporate the variation of growth rate over time into the population dynamics of this species. Exploratory model building continues to incorporate these concepts into an Integral Projection Model to test for effects of key demographic characteristic changes on the future population. This type of predictive model will allow the state and federal resource managers to better understand the impact of changes in the ecology or fishery to the long-term stability in the Hawaiian Black Coral fishery. A peer-reviewed publication is forthcoming during the 2020 calendar year.

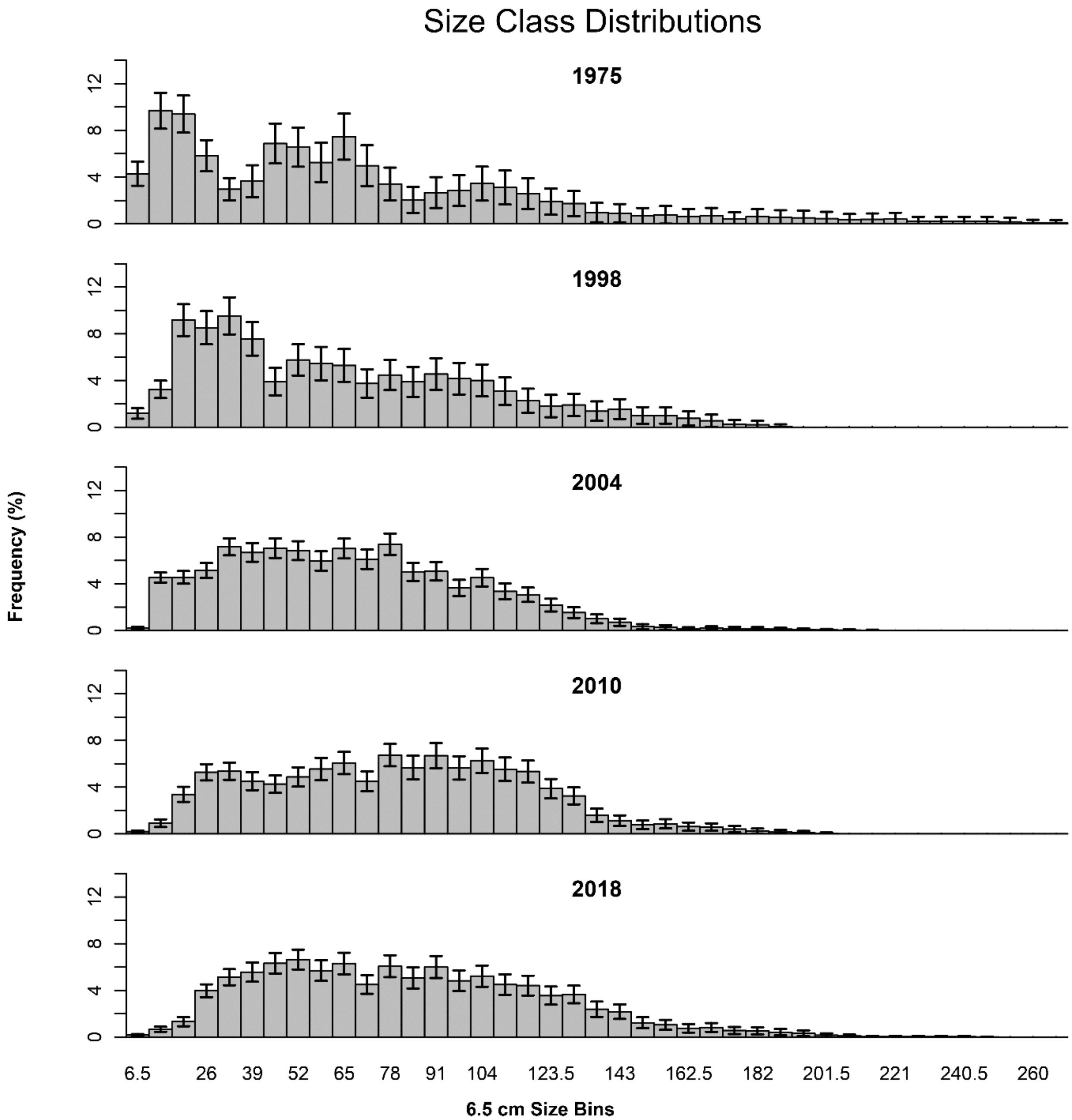

Figure 37. Size class distributions from 1975 to 2018 for *Antipathes griggi* in the Au'au Channel, Maui.

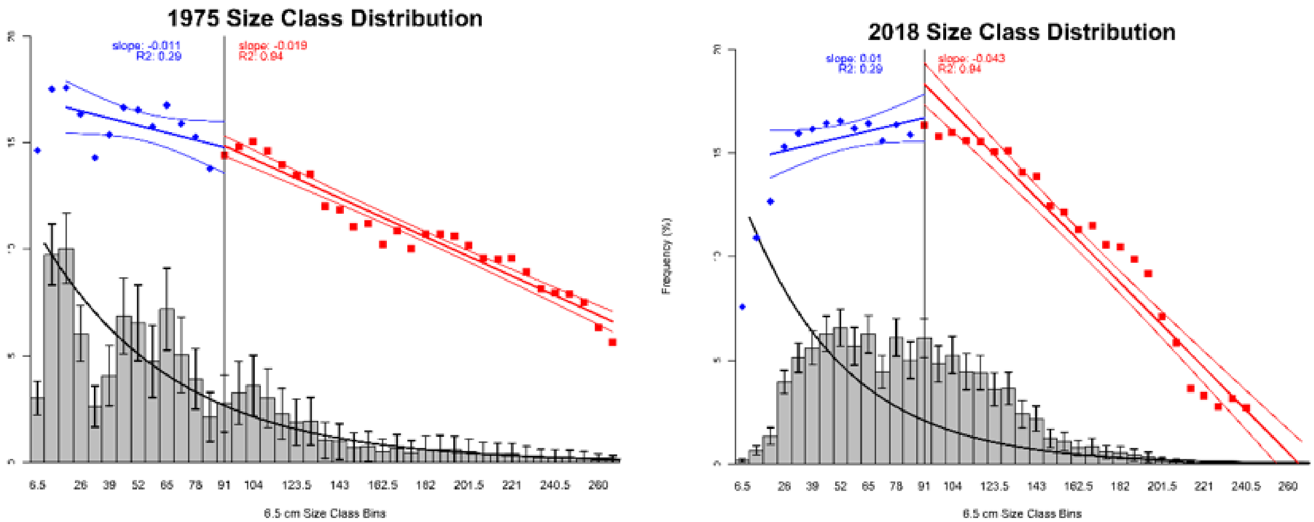

Figure 38. Size class distribution for 1975 and 2018 showing the regression slope indicating colony mortality for pre- and post-harvestable size classes.

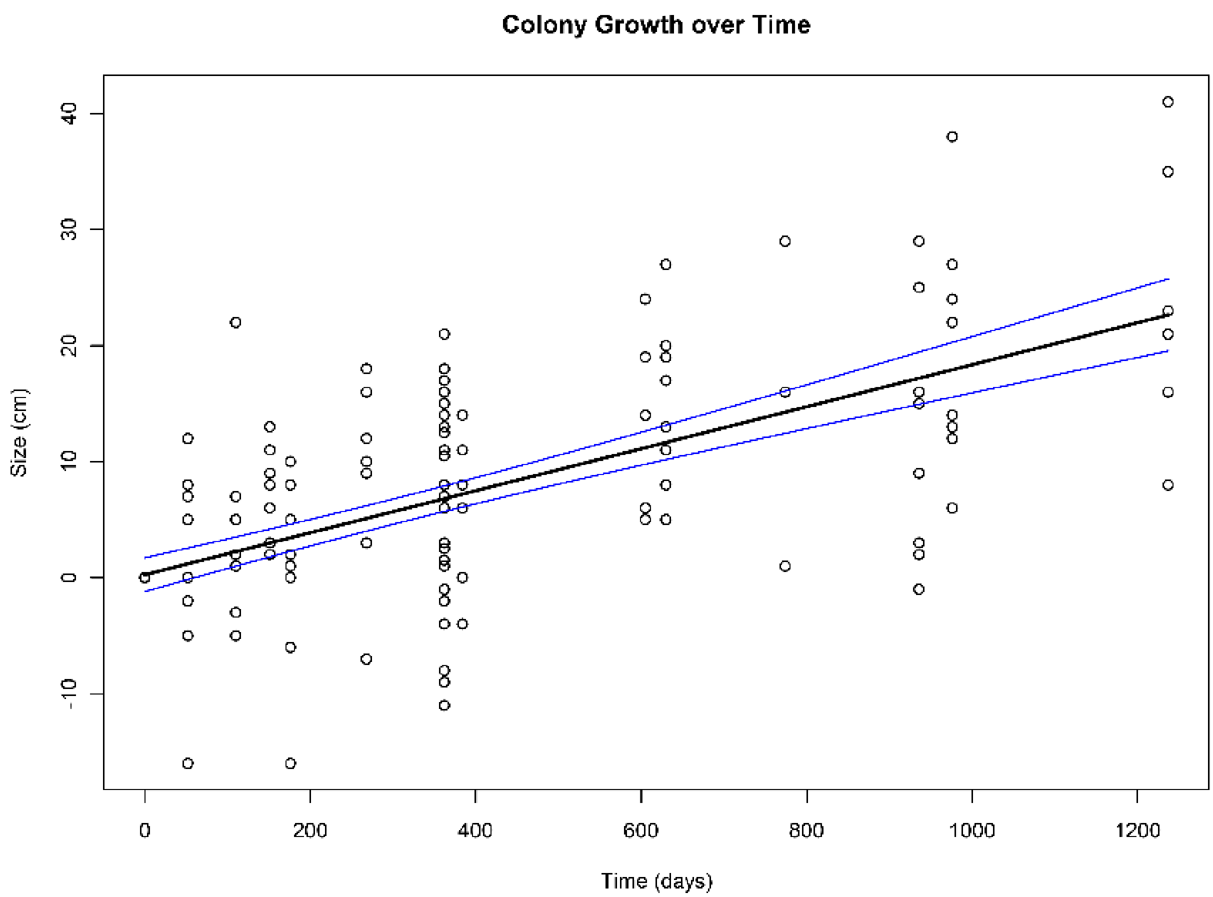

Figure 39. Growth rate graph normalized to cm of growth over days measured for 47 colonies.

In terms of molecular genetic work, the phylogenetics of the known Hawaiian antipatharian species were examined prior to conducting population connectivity research. This was to verify that the same species are being definitively identified across the Hawaiian Archipelago. During the early phase of this process, best extraction techniques for our samples had to be developed. Genomic DNA extractions were successful for 341 samples of interest, 18 for the phylogenetic study and 323 for the population connectivity study. The phylogenetic study includes 1 or 2 individuals of each of 10 recognized morphospecies (*Antipathes grandis*, *Antipathes griggi*, *Antipathes* sp., *Aphanipathes verticillata*, *Cirrhipathes* cf. *anguina*, *Cirrhipathes anguina*, *Cirrhipathes* sp., *Myriopathes* cf. *ulex*, *Myriopathes ulex* and *Stichopathes* sp.) and 4 distinct morphotypes of unknown taxonomic status within these morphospecies. These phylogenetic samples were prepared following a reduced representation genomic sequencing protocol modified from Johnston et al. (2017) that has now been optimized for antipatharians. The analyses from these samples are currently underway and led to sequencing the first complete mitochondrial genome for any Hawaiian antipatharian. Based on this, the species boundaries and taxonomic status of the Hawaiian Antipatharia are currently being reconstructed. Findings from this study have been invited for presentation at the 2020 International Coral Reef Symposium in Bremen, Germany.

In addition to this work being the first genomic analysis of species validity and relationships among the antipatharians, determining these species boundaries is a necessary first step in performing population genetic analyses to understand population connectivity and delineating management units. Once 323 samples prepared for the connectivity study have been sequenced, analyses will begin. These analyses should be completed over the course of the 2020 calendar year, and results from this work will be communicated to State and Federal resource managers as soon as they are available. Two peer-reviewed publications will report the results of each aspect of the project in open access format.

Project 6. Field surveys of SCUBA-accessible black coral populations in Hawaii and American Samoa to determine taxonomy and distribution of black corals.

Lead Investigator: Daniel Wagner – Conservation International
Collaborators: Randall Kosaki, Jason Leonard, and Brian Hauk – Papahānaumokuākea Marine National Monument; Wendy Cover – National Marine Sanctuary of American Samoa.

The objectives of this project were to characterize the taxonomy and distribution of commercially valuable Hawaiian black coral species (*Antipathes griggi*, *A. grandis* and *Myriopathes* cf. *ulex*) in Hawaii and to conduct a taxonomic survey of black coral populations accessible through mixed-gas technical diving off American Samoa. Between 2015 and 2016, Wagner conducted field surveys and specimen collections at 86 sites on 15 islands or seamounts from Hawaii Island to Kure at depths accessible through mixed-gas technical diving (50–90 m). More than 100 black coral specimens were collected and analyzed (Fig. 40). Using microscopy and morphological analyses, Wagner documented 6 different black coral species, along with five substantial range expansions, and confirmed that commercially viable populations of the 2 most commonly harvested species are only extant in the main Hawaiian Islands. This work was particularly important to managers responsible for developing regulations for coral extraction.

The second aspect of this research used mixed-gas technical diving to understand what black coral species exist at mesophotic depths in American Samoa, a depth range that has rarely been surveyed in the region. Previous to this work, only two black coral species had been reported from the American Samoa area. Field surveys and specimen collections were performed using trimix technical diving with the aid of closed-circuit rebreathers at depths ranging between 50–90 m. Black coral colonies were photographed in situ, and 3-cm samples were collected and preserved in 10% buffered formalin. Samples were prepared for scanning electron microscopy (SEM) (Wagner et al. 2010, 2011b) and viewed at the Biological Electron Microscope Facility (BEMF) at the University of Hawaii.

At 12 sites offshore of Tutuila Island, in depths of 35–100 m, Wagner collected 35 black coral specimens (Fig. 41) and tentatively identified 12 species, 10 of which are possibly new records for Samoa. He is still working to confirm species-level identifications for these corals. Wagner also collected 77 gorgonian specimens that are curated at Bishop Museum and being analyzed by Sonia Rowley.

Figure 40. Black corals from the Hawaiian Archipelago.

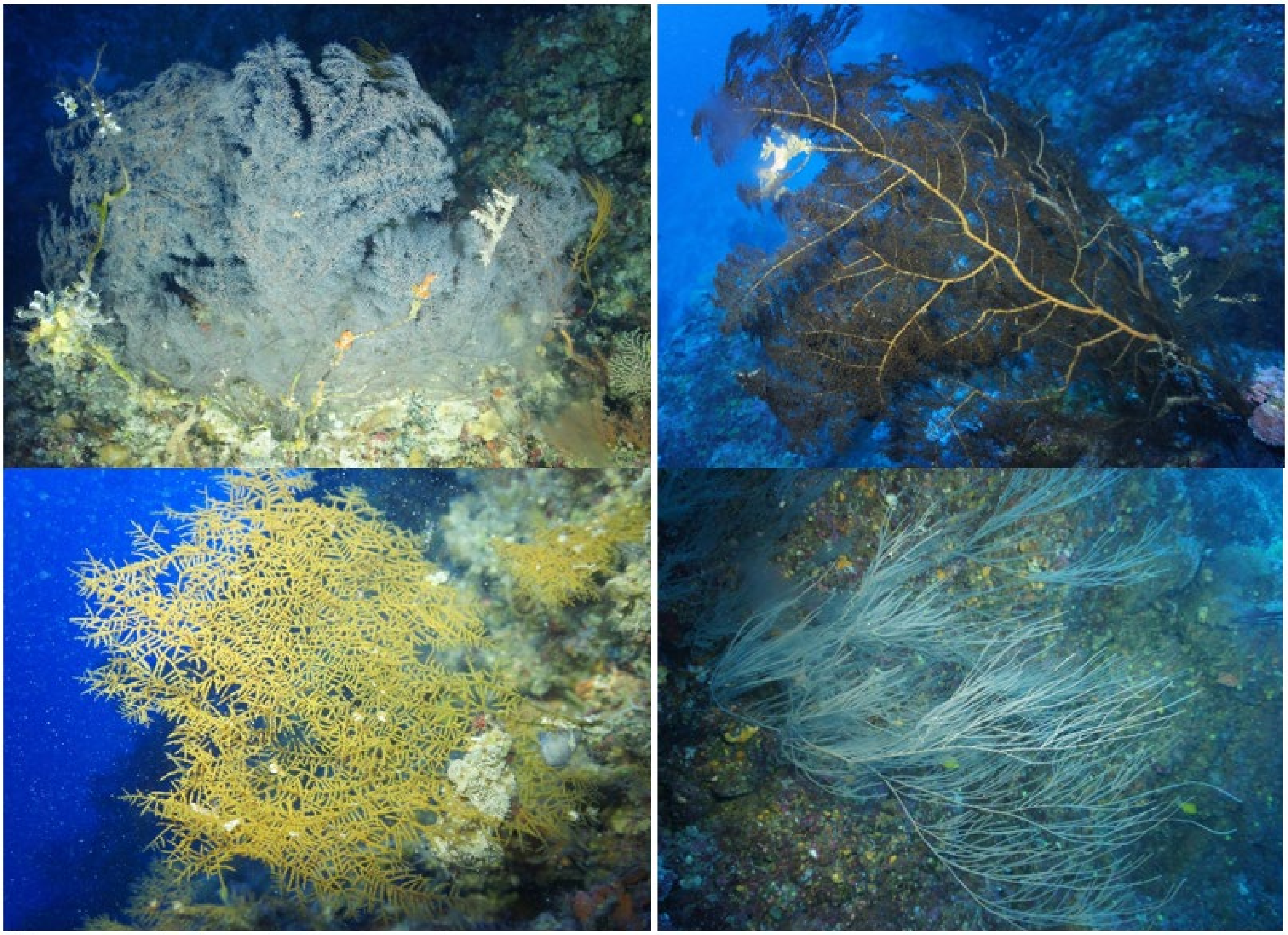

Figure 41. Black corals from American Samoa.

Project 7. Field and laboratory work to estimate community succession and recruitment rates in new habitat (e.g., lava flow).

Lead Investigators: Samuel Kahng – Hawaii Pacific University (skahng@hpu.edu), Meagan Putts – University of Hawaii (meagan.putts@noaa.gov)

Deep-water coral communities represent some of the most diverse and productive environments in the deep ocean. The skeletal morphology of corals provides habitat to numerous organisms, increasing complexity and biodiversity of the seafloor. However, many deep-sea corals are known to live well over 2,000 years and exhibit growth rates less than a millimeter per year, making these communities difficult to study within a human lifetime.

This project aimed to quantitatively measure the rate of colonization and describe stages of deep-water coral community development using Hawaiian lava flows. The volcanic activity in Hawaii continually generates new and overlapping layers of volcanic substrate. These lava flows, whose origins date from the Holocene to Pleistocene, can effectively act as large-scale 'coral settlement plates' (Fig. 42). This design also allowed for an investigation into the potential disturbance effect a new lava flow may have on the adjacent communities.

To characterize the development of deep-water coral communities, six submarine lava flows of successively increasing age (61, 134, 143, 400, 2000, and 2300 yr) were surveyed at three sites (Fig. 43). Each site (Ho'okena, Kealakekua, and Wai'o'ahukini) consisted of two lava flows of contrasting age: one of 'historical' age which occurred between 1950 and 1868 C.E. and the other was 'prehistoric,' between 1611 C.E. and 319 B.C.E. In addition, a fourth site (Keāhole) located on a drowned fossil carbonate platform, estimated to have been at deep-water coral depths for 15,000 yr, was surveyed as an example of a more mature coral community to contrast with the younger lava flow sites.

Transect surveys were conducted using the Hawaii Undersea Research Laboratory (HURL) submersible *Pisces V* (28−30 September 2011) and the remotely operated vehicle (ROV) *Deep Discoverer* belonging to NOAA Ship *Okeanos Explorer* (30 August 2015) at depths of 400 and 450 m. The video was analyzed to characterize the geomorphology and community composition at each site and on each lava flow.

This was the first study to examine the rate of growth of a deep-sea coral on a community scale over 100+ year time frame. Furthermore, Hawaii is probably the only place in the world where such a study could have been performed due to its continuous and widely understood volcanology. This work suggests that the development of a community with mature pink corals, Coralliidae, can occur within ~150 years (Fig. 44) while the development of a community of larger, slow growing corals, like the gold coral *K. haumeaae*, could take thousands of years. These findings will have important implications for the conservation and management of deep-sea ecosystems.

A pattern of ecological succession is evident within deep-sea coral communities that extends over time scales of centuries to millennia (Fig. 45). Initially, the relatively fast growing Coralliidae, which reach maturity within 60–100 years, were the pioneering taxa colonizing new lava flows first and dominating the community. With enough time, the community shifted toward supporting a more diverse array of tall, slower growing taxa including Isididae (bamboo coral) and Antipatharia (black coral). The last to colonize was *K. haumeaae* which is parasitic in nature, over-growing mature bamboo corals, and also the slowest growing taxa within the community, increasing in diameter at just 0.04 mm a year.

However, the community composition on the prehistoric lava substrates (400, 2000, 2330 yr) did not exhibit the expected developmental stage relative to substrate age but reflected that of a much younger community similar to that on the adjacent younger 'historic' lava flow (Fig. 44 and Fig. 45). Multivariate analyses suggest that this similarity decreased with distance from the historic flow indicating that this pattern could be explained by a disturbance effect from the new lava flow. High volume submarine lava flows can cause high coral mortality due to elevated water temperatures, changes to the hydrodynamic regime due to alterations in the local geomorphology, and altered water chemistry.

Local environmental conditions, shaped by the topography of the lava flows, influence the hydrodynamic regime. In agreement with previous studies, there was a strong association between coral abundance and high relief features such as ridges, crests, and boulders (Fig. 46) which are areas of current acceleration.Therefore, these locations deliver higher rates of food supply.

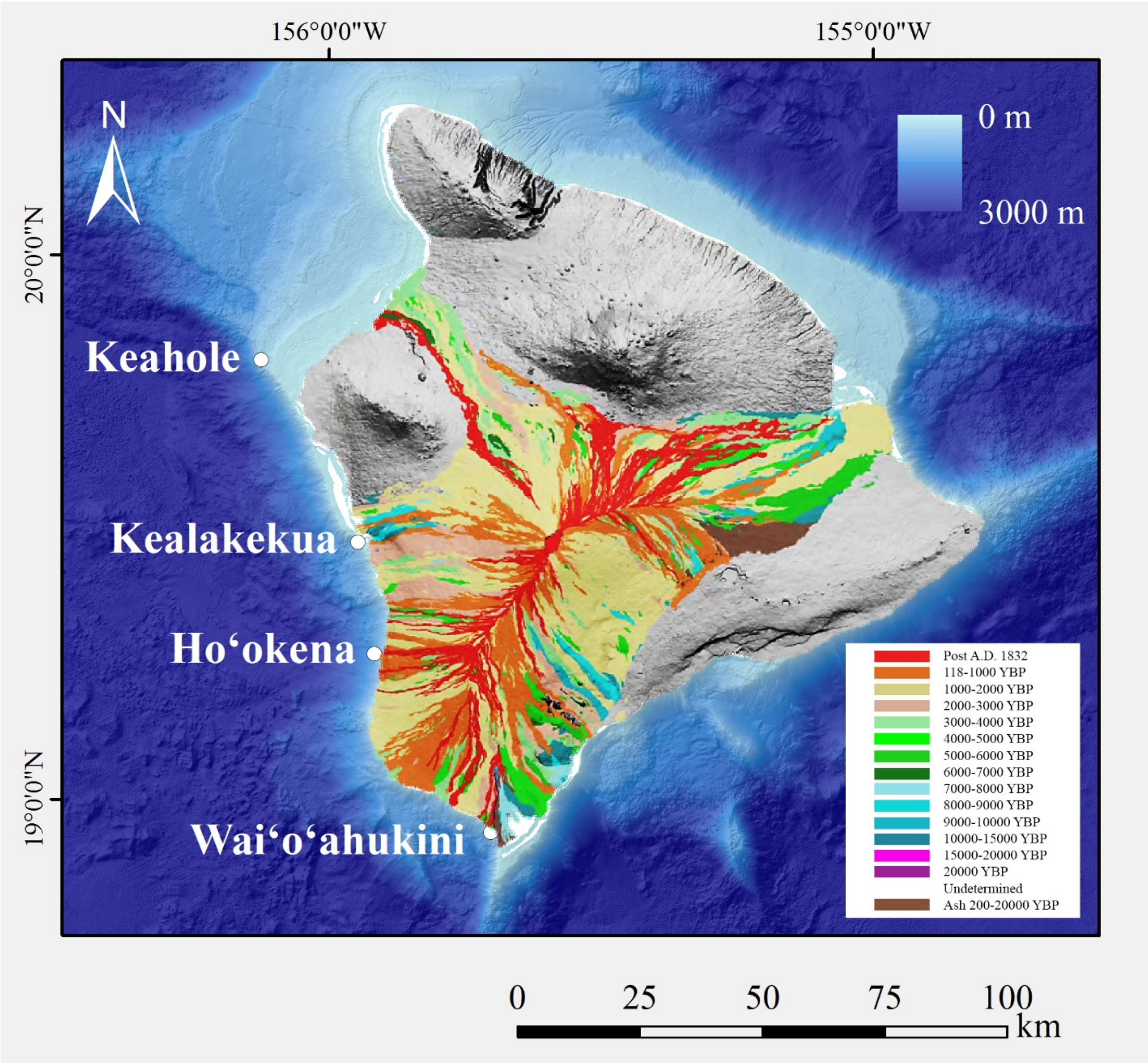

Figure 42. Boundaries of Mauna Loa lava flows on the Island of Hawaii with age as years before present (YBP) shown in color (ranging from oldest in purple to most historical in red; 1:50,000 scale). Labeled place names indicate the general location of the 4 deep-water coral survey sites.

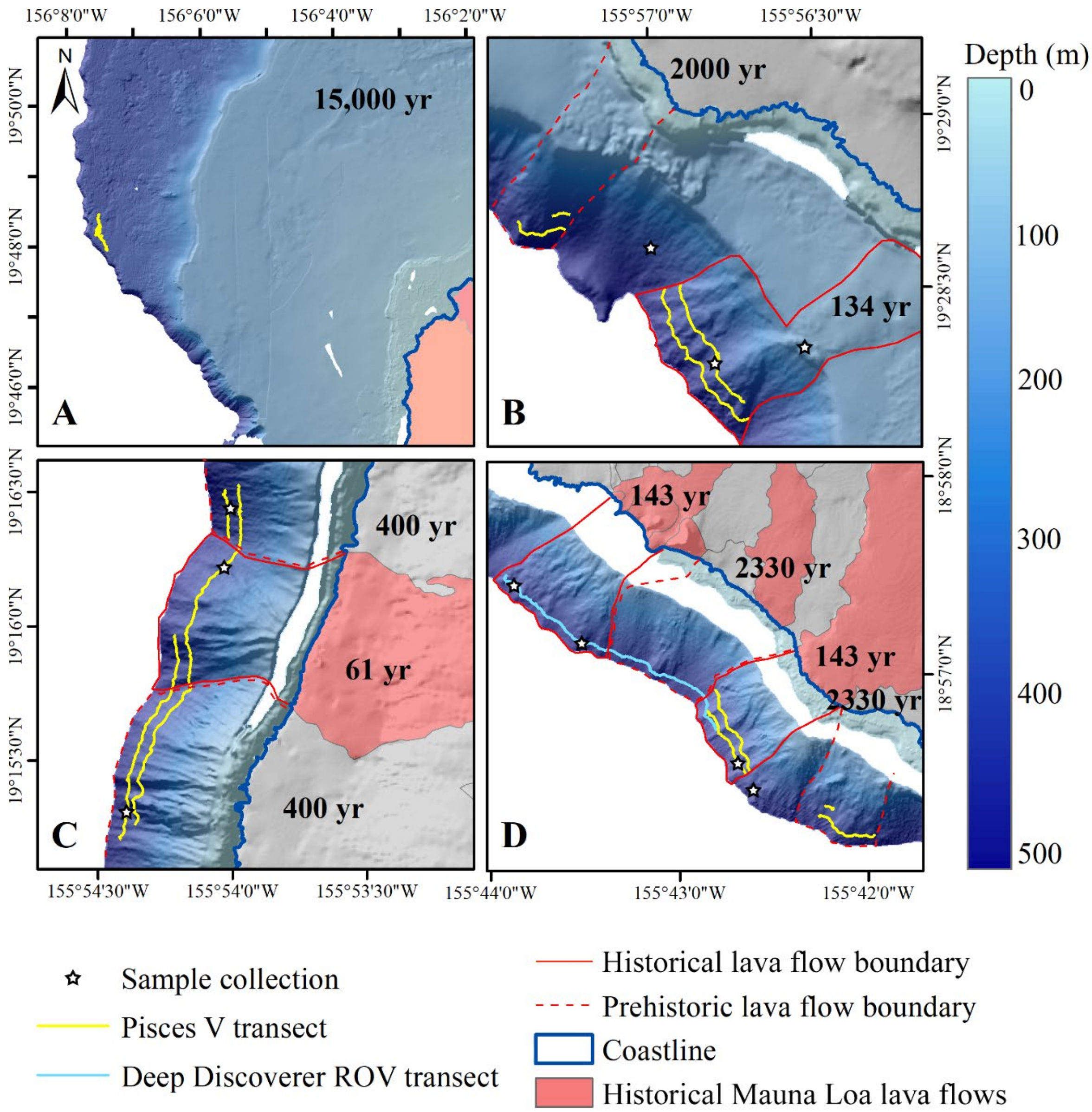

Figure 43. Maps of survey sites (A) Keāhole, (B) Kealakekua, (C) Ho'okena, and (D) Wai'o'ahukini. Transects lines of the submarine '*Pisces V'* (yellow) and ROV '*Deep Discoverer'* (blue) survey at each site. Lava flow boundaries are traced in solid red for historical lava flows and dashed red for prehistoric flows, with the age of the substrate indicated.

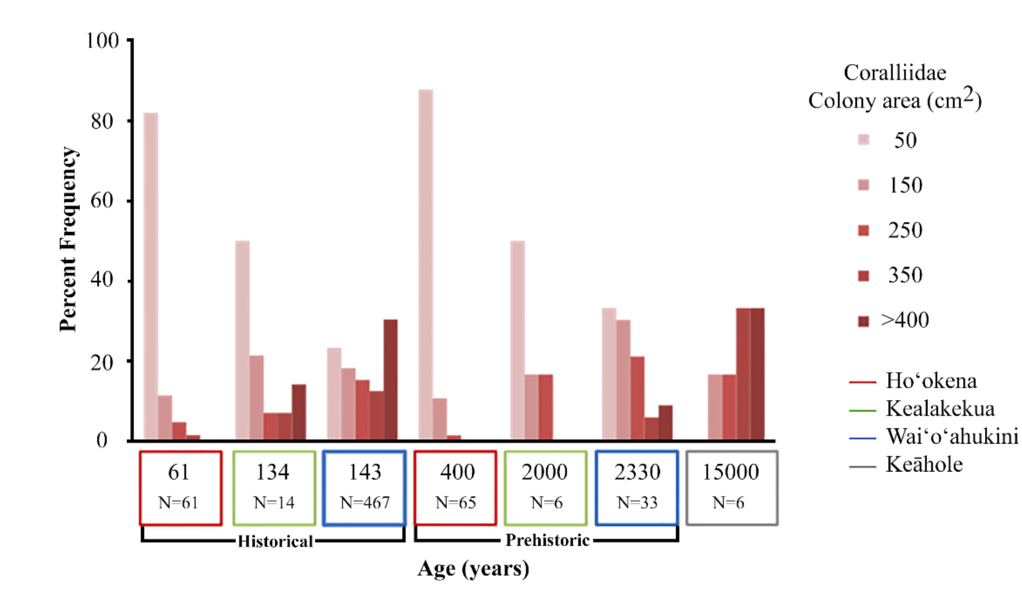

Figure 44. Size-frequency distribution of pink corals, Coralliidae, on aged substrates. Color boxes indicate spatially adjacent substrates: Ho'okena (red), Kealakekua (green), Wai' o'ahukini (blue), and Keāhole (grey). The number of colonies measured is indicated below the substrate age.

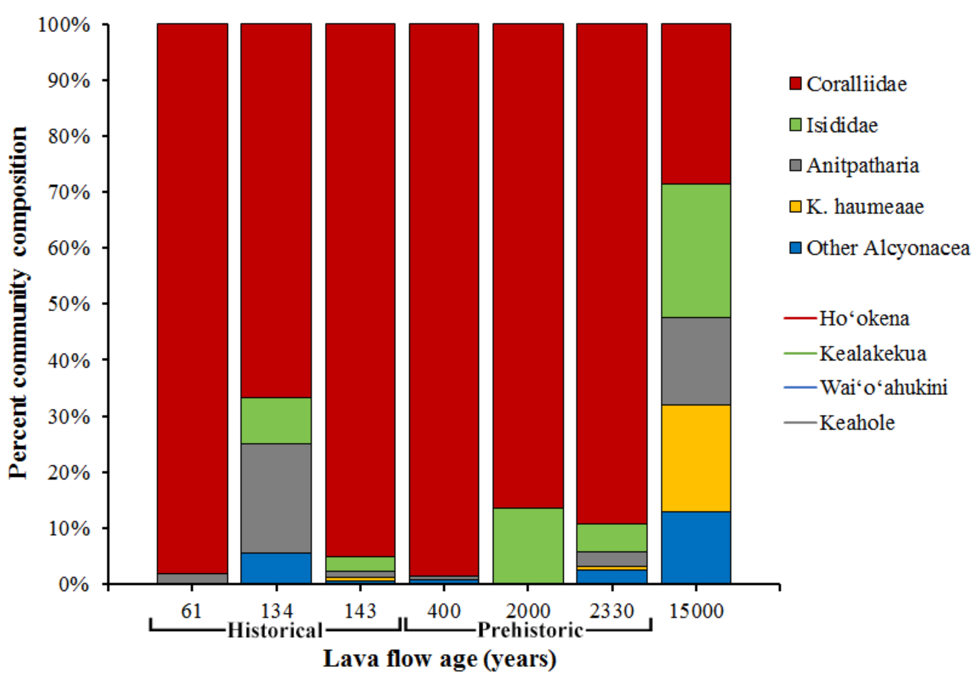

Figure 45. Community composition of the major deep-water coral taxonomic groups, Coralliidae (red), Isididae (green), Antipatharia (grey), Kulamanamana haumeaae (yellow), and other Alcyonacea (blue) on aged substrates. Color boxes surrounding the flow age indicate spatially adjacent substrates: Ho'okena (red), Kealakekua (green), Wai'o'ahukini (blue), and Keāhole (grey).

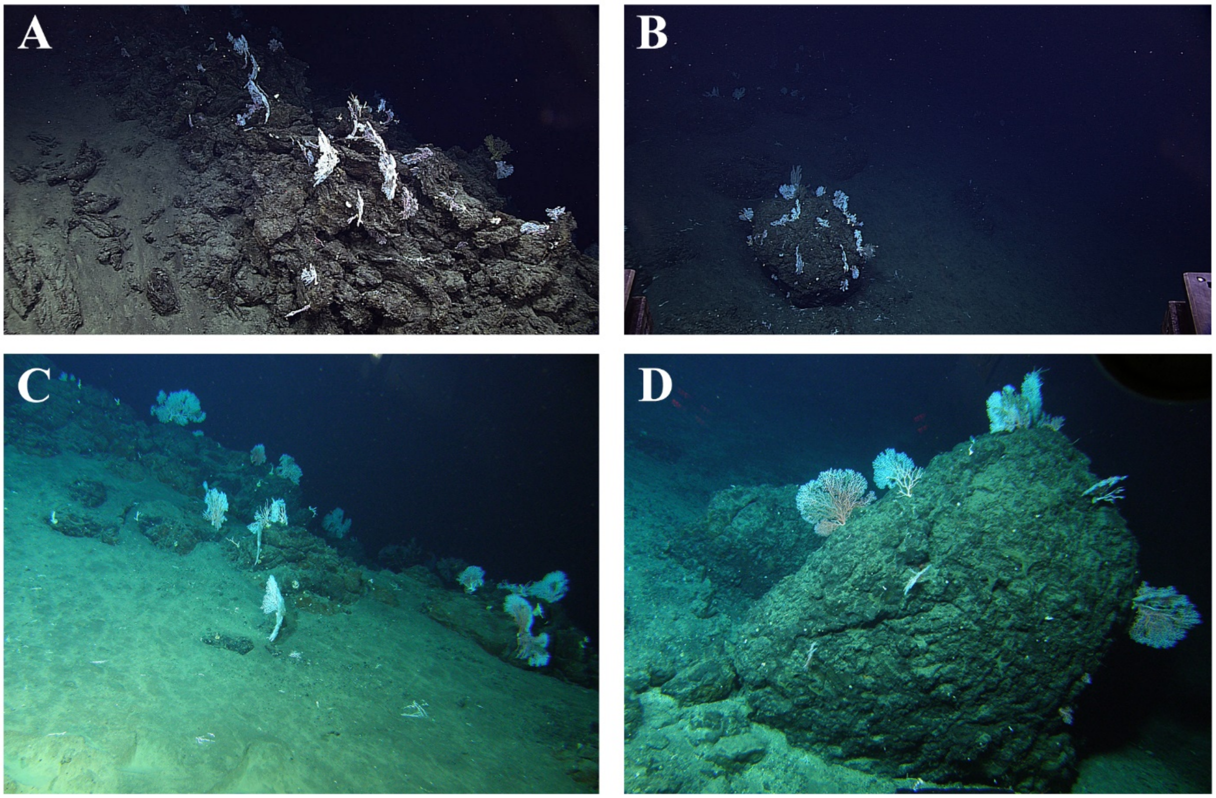

Figure 46. In situ imagery of coral colonies clustered exclusively on the tops of (A,C) ridges and (B,D) boulders— areas where the bathymetric position index (BPI) is highly positive.

Project 8. Instrumentation and environmental monitoring. Field work to collect data on temperature, current direction, and flow rate from deployed instruments in known precious coral beds.

Lead investigator: Frank Parrish – NMFS- Pacific Islands Fisheries Science Center

Collaborators: Tom Oliver, Amy Baco-Taylor, and Brendan Roark

Deep corals are inherently patchy, and little is known about what governs where they settle and grow. Two decades of surveys in the main Hawaiian Islands have provided good information on the locations of different patches of deep corals and have prompted questions about why certain corals occur in some areas and not others. Some coral patches are dominated by one species where other patches contain multiple species. It is not clear why some identical substrates at similar depths have coral and others do not. Hard substrate and adequate current flow over these substrates are clearly important, but minimum and maximum flow rates in these areas, and how they change over time are unknown. As suspension feeders, corals eat the organic material carried by the passing water column so the rate of flow may affect food delivery, community composition, and size structure. Many deep-sea corals grow extremely slowly. Once damaged, it is unknown how long individuals and communities take to recover, if they recover at all. Ocean acidification may also affect the ability of deep-sea coral and sponges to grow and maintain their calcium carbonate structures.

Parrish and Oliver used submersibles to collect environmental data loggers that had been opportunistically deployed over the last few years to measure and monitor the flow direction, speed, and tidal spectra of the seafloor water movement through patches of deep-sea corals at 3 topographically different sites and determine the relationship between these variables and recovery rates. An acoustic current meter and multiple flow meters with thermographs were still on the bottom waiting for recovery. During the PIDSCI, all the instruments placed in and adjacent to deep-sea coral beds to characterize their environment were successfully recovered (Fig. 47) and their data used to create a coordinated approach to document environmental differences at established sites.

After collecting data for 7–30 months, the 15 instruments were recovered from 3 sites where the sea floor morphology and the dominant coral community differed. One was an even-bottom site dominated by Coralliidae, a second was a ledge-top area with primarily Keratoisidinae and *Kulamanamana haumeaae*, and the third was a pinnacle summit with *K. haumeaae*. Instruments sampled between 7 and 30 months with the average flow rate found to be slowest (4.5 cm/s) at the ledge-top site. The fastest flow rate (13.6 cm/sec) was seen at the even-bottom site where the direction of the current remained the most consistent. Tidal forces were important at all sites but there were significant differences in the spectral cycle. A greater range of directions in the flow was seen at the ledge-top site which was located on the west coast of the Island of Hawaii, versus the two other beds located at the southeast end of the island of Oahu (Fig. 48). More localized differences in flow rates within each coral patch were identified using independent flow meters placed to get a range of values acceptable to coral settlement and growth. Understanding the composition of these coral assemblages and relating in situ environmental observations to broader-scale oceanography can improve our ability to model deep-sea coral occurrence.

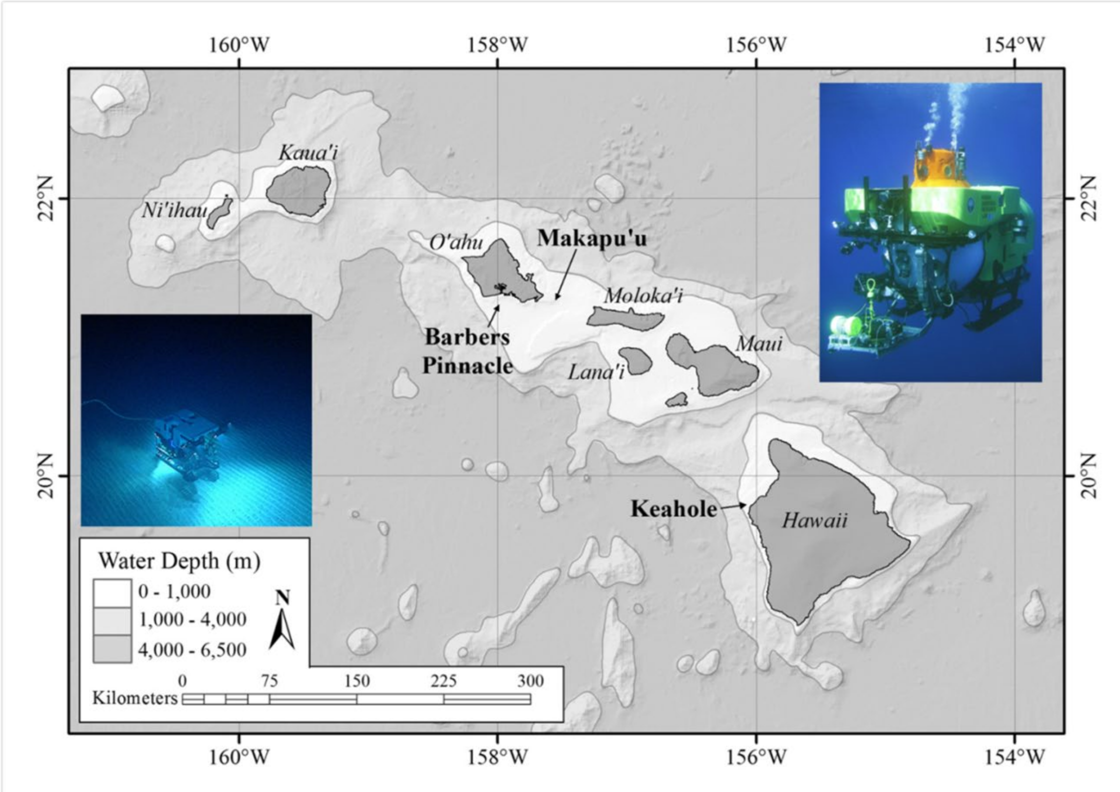

Figure 47. Location of 3 deep coral patches studied in the main Hawaiian Islands with photo insets of the *Deep Discoverer* ROV and *Pisces V* submersible used to recover the instruments.

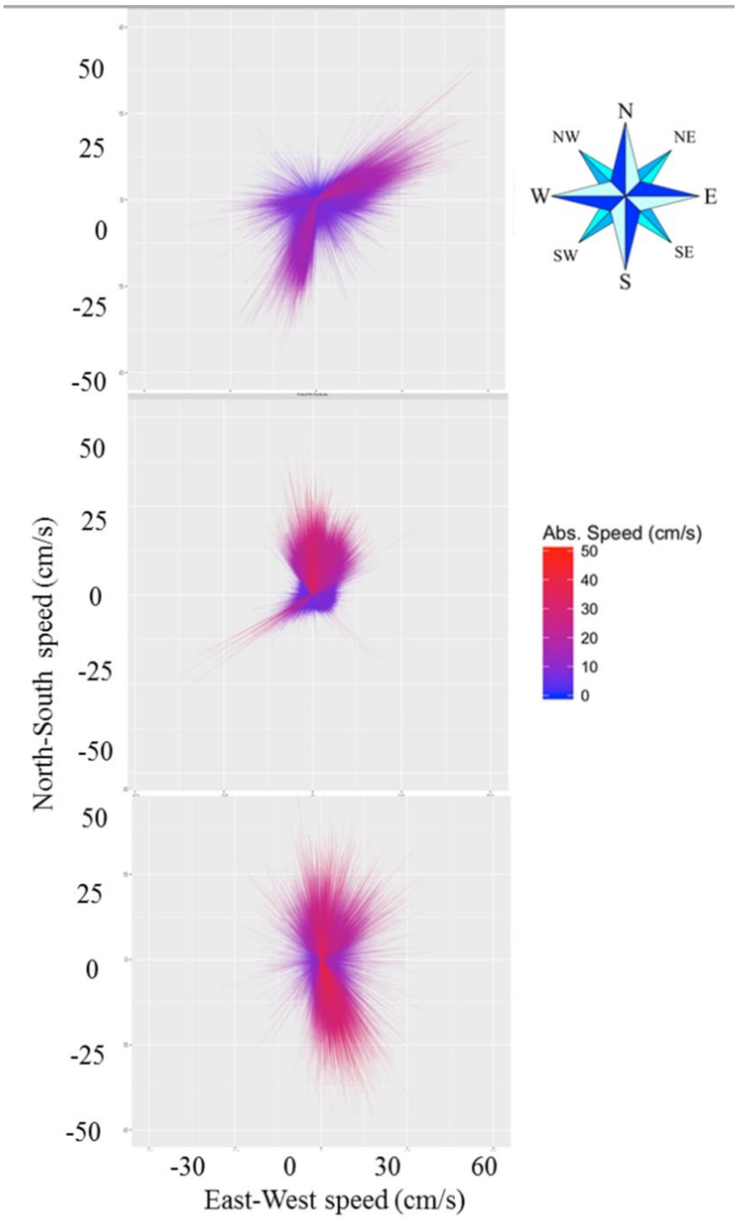

Figure 48. Flow rose plots for the 3 sites monitored; top is the pinnacle site (Barbers), middle is the ledge-top site (Keahole), and bottom is the even-bottom site (Makapu'u).

Mean flow rates from instruments placed next to individual coral colonies differed significantly by taxa for the 19 coral taxa observed. Some corals were seen at only one site, while others were measured at all sites. Patches of coralids included the "red" *Hemicorallium laauense* " found with lowest flow (0.5–4.9 cm/s) and the "pink" *Pleurocorallium secundum* seen at a higher-level flow (12.6–18.4 cm/s) level. *Narella gigas* and *N. muzikae* were observed as a patch at one site which had the highest flow (18.4–21.7 cm/s). All three sites had bamboo coral (*Acanella dispar*) and the parasitic zooanthid, gold coral (*Kulamanamana haumeaae*) that colonizes where flows range from (2.8–18.9 cm/s). For this group, there was a possible effect of flow on the size structure. Colony size of gold corals was negatively correlated with increasing flow, but this was not seen for their bamboo host colonies. Although preliminary, these observations provide some insight as to how flow regimes form patches of colonies and influence diversity in deep-sea coral communities (Fig. 49).

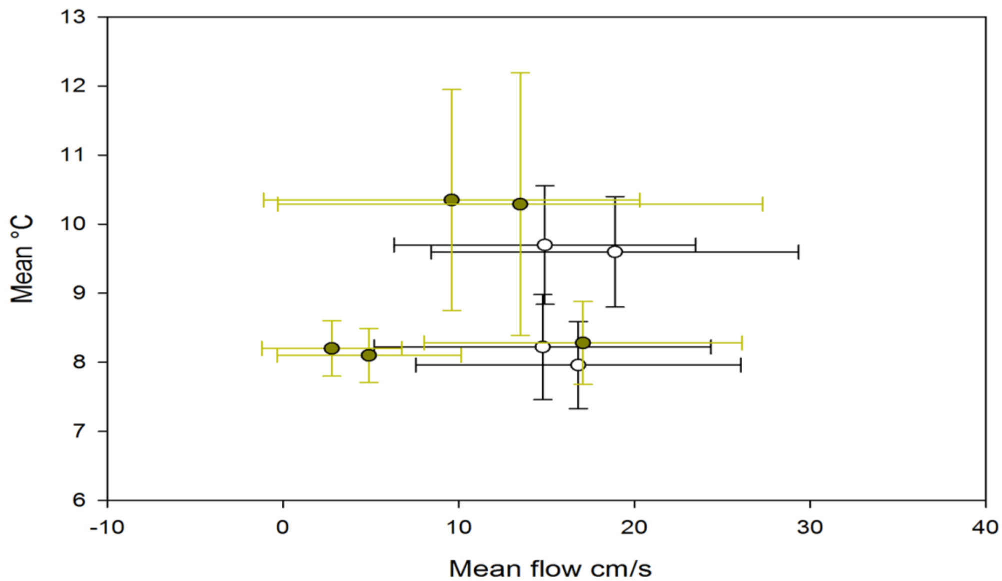

Figure 49. Mean (and std) of flow rate and temperature from instruments placed next to colonies of the parasitic gold coral and its bamboo host. Dark dots are the gold colonies and white dots are the bamboo colonies.

Tidal extremes pushed max flow speeds to as high as 95.3 cm/sec, but high speed did not guarantee a patch would have higher density or diversity of deep-sea corals. The low flow patch and one high flow patch showed higher diversity (15–28 taxa) and average number (0.9–7.13 colonies/meter traveled) than the patch where the max flow was recorded (11 taxa and 0.20 colonies/meter traveled). The data from the placement of multiple instruments within a patch showed variability consistent with topographic influences on flow rates (e.g., ridges versus sheltered substrate). Study sites with higher average flow showed coral community patterns with higher populations of *Acanthogorgia* sp., Coraliidae, *Lepidisis olapa*, Primnoidae, and *Thouarella hilgendorfi*; the two sites with the lower flow rates had more *Kulamanamana haumeaae* and Plexauridae. Sponges (e.g., *Characella* sp. Hexactinellida sp. *Regadrella* sp.) were seen only at the two high flow sites. Comparisons of the tidal spectra at the three locations show obvious differences among the three patches and tidal flows are critical to understanding colonization patterns of deep coral and sponge communities.

Finally, as part of the Musician Seamount leg of the CAPSTONE initiative, a dive visited the hull of the WWI submarine *S-19* that rests on the bottom within a km of a patch of mature gold corals. The hull was scuttled approximately 75 years earlier and was surveyed for colonization by deep water corals. The goal was to find patterns that would confirm inferences about deep coral life history made from observations of natural deep coral patches. The survey identified a number of bamboo colonies growing on the hull, one big enough to be 50 years in age. There were no colonies of the slower-growing gold corals and none of the bamboo colonies had yet been colonized by gold coral planula that would transition to gold colonies.

Associated research on Pacific Islands deep-sea corals and sponges

Amy Baco-Taylor and Brendan Roark conducted exploratory surveys to monitor the recovery of seamount precious corals from trawling disturbance and fisheries impacts on the northwestern Hawaiian Ridge and Emperor Seamount Chain seamounts. This National Science Foundation-funded research was conducted primarily at three areas that had either been fished continuously, had been fished in the past, or had never been fished (treatment types). Precious corals, pelagic armourhead (*Pseudopentaceros wheeleri*), and alfonsino (*Beryx splendens*) had all been extracted from these areas in the past. Using the Hawaii Undersea Research Laboratory's (HURL) *Pisces 4* and *5* and autonomous underwater vehicle (AUV) *Sentry*, they conducted 242 video transects on 72 science dives at 12 different seamounts, covering a distance of 121 kilometers. They collected voucher specimens of dominant fauna, more than 800 genetic samples of Coralliidae, and over 300 aging-paleo samples. On their multiple endeavors, they deployed and successfully recovered the environmental lander that had been placed in coral beds at various locations at approximately 500 m depth. This lander provided Roark with a nine-month record of data on currents, conductivity, temperature, depth, and fluorescence (Fig. 50).

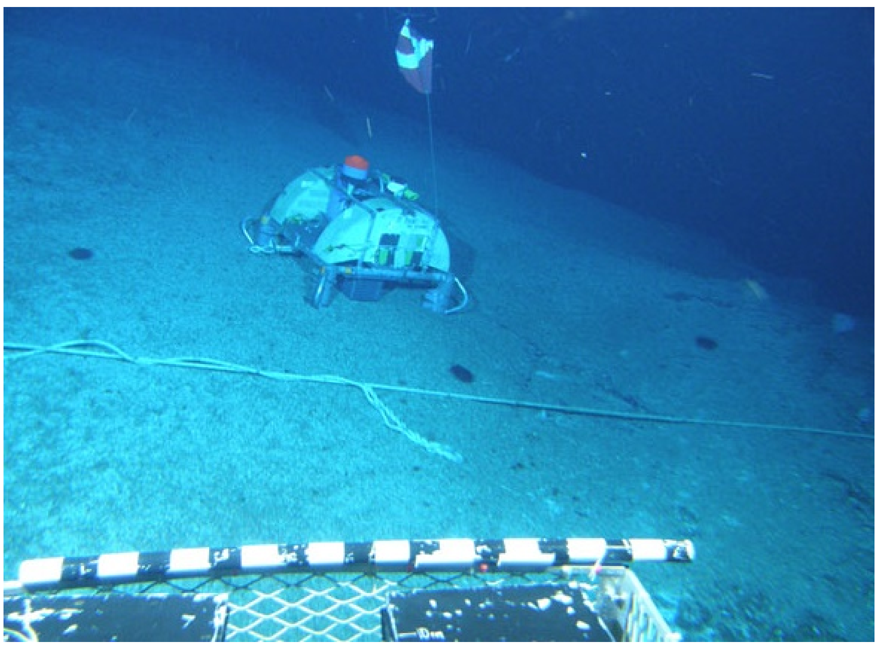

Figure 50. Environmental lander deployed on Hancock Seamount with old fishing gear in the foreground.

They examined species composition, abundance, and diversity of megafauna between the seamounts of the three treatment types, looked at age structure to determine the time it takes for corals to recolonize after the cessation of trawling, and examined the genetic structure of actively disturbed to recovering beds. Baco-Taylor and Roark discovered massive impacts from trawling, with obvious and substantial damage even in areas no longer fished, and found soft corals often the dominate megafauna, suggesting that some of the disturbed ecosystems have moved to alternate states. Localized coralliid recovery or regeneration is believed to most likely be from *remnant* populations. Baco-Taylor continues to examine recovery rates, the kinetic effects of growth rate (slow/fast radial growth axes within a sample), the natural environmental gradients (200–800 m) of temperature, pH, and aragonite, intraspecies variation by depth, interspecies differences, and the variations in carotenoid content (which determines coloration and commercial value of precious corals).

Baco-Taylor has partnered with various academic and research institutions by providing samples to further genetics work that will distinguish CITES-listed and non-CITES-listed precious corals, determine Mg content in calcitic octocorals using Raman systems at high resolution (~2 µm), and examine the trophic relationships of subphotic antipatharians. These relationships will be determined through the investigation of nitrogen assimilation for subphotic black corals with photosymbiotic dinoflagellates (Symbiodiniaceae) using compound-specific (amino acid) stable isotope analyses (δ 13 C, δ 15 N).

Roark is still processing data recovered from the Deep-Sea Coral Lander developed with DSCRTP funding. Using results from long-term deployments at Pioneer Bank and Hancock Seamount at ~500 m depth and other water chemistry data collected throughout their voyage, he has determined that the Aragonite Saturation Horizon (ASH) deepens (500–650 m) moving NW along the NWHI with corals living in undersaturated water. He and Baco-Taylor believe that factors contributing to reef presence or absence include chlorophyll, high speed currents bringing nutrients, and other environmental parameters. Roark and Baco also plan to develop colony height-to-age and growth-rate curves using direct measurements of height, width, and diameter along with radiocarbon dating; these results will be used to determine the various size and age classes of coralliid across multiple seamounts in the NWHI.

Sam Kahng conducted research on the geochemistry of deep-sea corals in Hawaii. Working with samples of marine carbonates and different Coralliidae and Isididae species collected off of the west coast of Hawaii Island from 2011 to 2017, Kahng used electron microanalysis to measure stable isotope concentrations of carbon, boron, oxygen, and nitrogen in an attempt to develop geochemical environmental proxies for Hawaii precious corals. He collected a 2011–2017 time series of CTD data over a variety of depths in west Hawaii and high-resolution temperature data from data loggers at ~100-m depth intervals for one year (2017) to explore and model environmental versus vital effects for these species. Kahng stressed that this geochemical work is just beginning and will be ongoing for a few years. The work is beginning with Mg/Ca ratios correlating to in situ temperature at different depths. On a small subset of Corallidae samples, geochemical parameters (δ 13 C, δ 18 O, δ 11 B, Mg/Ca, S/Ca, Ba/Ca,Sr/Ca, F/Ca, Cl/Ca) were measured via NanoSIMS and correlated against temperature, pH, DIC at each depth and across time to use as potential paleo environmental proxies. Dr. Kahng also conducted a 2-sub HURL dive to add to his study of coral communities growing on lava flows of known age on the Big Island of Hawaii. Visiting a new site, he conducted a cross contour transect of the coral community starting at 900 m and working to the edge of the photic zone at 220 m where he found the shallow edge of the corallium bed. On the way up slope, he collected samples and placed thermographs at roughly 50-m intervals. He also collected coral samples (Corallidae and Isididae) and high-resolution temperature data from 2016–2017. Finally, Kahng worked with collaborators to explore the phylogeny of Coralliidae and Isididae. Tissue samples were analyzed for morphology and molecular genetics to identify species/clade and phylogeny. Laboratory analyses have been completed and will be integrated into future manuscripts.

Santiago Herrera examined the biodiversity transitions in the deep Pacific Ocean around American Samoa and the Samoa Passage. He worked with data collected during *OE* missions in American Samoa and marginally-explored surrounding waters. American Samoa lies at the boundary of four major bathyal biogeographic provinces and thus is a key area to understand the biodiversity transitions that occur in the deep Pacific Ocean. The Samoan Passage north of the American Samoan islands is a major circulation gateway for deep water flowing from the Southern Pacific into the Northern Pacific, and it may also constitute a significant barrier for larval dispersal. Consistent with this hypothesis, Herrera observed that coral communities found between 250 and 4,000 m in the American Samoan region were distinct from those north of the passage (e.g., precious and bubblegum octocorals, as well as sea pens were not observed in American Samoa, but were observed in other CAPSTONE expeditions). The coral and sponge communities within the American Samoan region appear to be largely structured by depth. He also found that the timing of recent undersea volcanic eruptions is associated with an apparent pattern of ecological succession of the benthic communities living in the crater. He has examined the biological samples collected in this region and found that as many 40 of the specimens collected and/or observed during this expedition could represent new species, including one of the deepest ever live sightings and ecological data for an undescribed species of a monoplacophoran mollusk.

Bryan Costa and Matthew Poti from the NOAA National Center for Coastal and Ocean Science (NCCOS) developed deep-sea coral models to support targeted exploration around the main Hawaiian Islands. One objective of PIDCSI was to map and characterize new deep-sea coral and sponge ecosystems around the U.S. Pacific Islands and main Hawaiian Islands (MHI). Around the MHI, existing deep-sea coral records from NOAA's National Database for Deep-Sea Corals and Sponges and the Hawaii Undersea Research Laboratory were concentrated mainly on Cross Seamount, Makapuʻu Point, Makalawena Bank, Lōʻihi Seamount, and the southern edge of Penguin Bank. NOAA NCCOS used these deep-sea coral observations to create spatially explicit predictive models for eighteen deep-sea coral groups and identify unexplored areas likely to contain suitable habitat for these taxa. While initially created for BOEM, these models were subsequently used to inform two ROV dives from the NOAA Ship *Okeanos Explorer* on two unexplored seafloor features (i.e., Middle Bank and the Tropic of Cancer Seamount). Although there were no prior records of deep-sea corals on these seafloor features, NCCOS's models predicted that they contained highly suitable deep-sea coral habitat for several taxa. During the ROV dives, red and pink corals (Coralliidae), gold corals (*Kulamanamana haumeaae*), and black corals (Antipatharia) were documented for the first time on Middle Bank. Several different species of deep-sea corals were also seen on Tropic of Cancer Seamount, including bamboo corals (Isididae), bubblegum corals (Paragorgiidae,) black corals (Antipatharia), and mushroom corals (Alcyoniidae). These ROV dives suggest that—on these two seafloor features—NCCOS's models were successful in predicting suitable habitat for deep corals and they were useful for guiding targeted exploration efforts by the PIDSCI in the MHI.

Conclusion

The PIDSCI used its May 2014 workshop to engage scientists and resource managers representing stakeholders from government, academia, and conservation groups to identify critical information needs for deep-sea coral and sponge ecosystems and to develop a three-year exploration and research priorities plan for the Pacific Islands Region. Using DSCRTP funds to facilitate partnerships, between 2015 and 2017, the PIDSCI completed projects in the Pacific Islands region that were identified as priorities in the 2014 planning meeting. These included efforts to: (1) retrieve information from existing data and develop effective and efficient practices to make these and more recently collected data available for future analyses, field work planning, and resources management; (2) to characterize the biogeographic patterns of coral's and sponges' distribution; (3) document the depth distributions of corals and sponges, especially between 500 and 4,000 m; (4) document the life history and genetics of black corals in the MHI; (5) examine growth and reproductive rates of black corals in the MHI and taxonomy of black corals in American Samoa; (6) determine colonization and succession rates on lava flows off the Big Island; (7) measure growth and succession rates of bamboo and gold corals in Hawaii, and examine some of the environmental factors affecting the distributions of deep-sea corals and sponges, and how these factors might affect biogeographic modeling efforts; and (8) examine the life history traits, genetic factors, and growth characteristics that affect resilience in deep coral and sponge assemblages and influence the ability of and time needed for deep-sea coral or sponge communities to recover from disturbance.

A 2018 wrap-up workshop elucidated how these exploration and research results support improved scientific understanding of deepwater biogenic habitats in the Pacific Islands and current or future management information needs, particularly those of the Western Pacific Fishery management Council and the Pacific Islands Marine National Monuments. The workshop also identified remaining research needs in the U.S. Pacific Islands region and provided recommendations for future Deep-Sea Coral Research and Technology Program's partnerships and fieldwork. Participants concluded that the CAPSTONE mission provided a rich set of data that can be mined and analyzed for years to come. The NOAA Ship *Okeanos Explorer* (*EX*) spent 431 days at sea, mapped over 635,000 km^2, conducted 187 ROV dives at depths ranging from 250 to 6,000 m, collected 333 primary biological (along with many still uncounted commensal organisms) and 278 geological samples, actively engaged more than 260 participating scientists, students, and managers during ROV dives, and streamed over16 million views of live video feeds of the expedition. They also agreed that the CAPSTONE survey methods do not lend themselves to quantitative analyses. CAPSTONE provided the main research vessel through the 3-year program, but other projects independent of CAPSTONE were initiated and data analyses continue for those projects.

Did the project successfully answer the five priority questions posed in 2014? Though still nebulous, our research suggests that source populations, currents, oxygen, particulates, and chlorophyll are important environmental factors affecting deep coral distribution. The geographic scope of the CAPSTONE mission, combined with taxonomic research on black corals, has enabled us to make some early inferences regarding the biogeographic patterns at the Pacific basin scale. Ongoing research continues to contribute to our understanding of the timeline involved in deep-coral communities' recovery from disturbance. UH researchers have provided a tremendous service by extracting the data from long-archived HURL data sets. Although not definitive and subject to the taxonomic limitations of the surveys, we have preliminary indications that some corals can thrive even beyond 4,000 m depth, but that most seem to prefer depths shallower than 2,400 meters.

The PIDSCI has advanced our knowledge of the ecology of deep-sea corals and sponges in the U.S. Pacific Islands, so that management of these resources can be based on a scientific understanding of how humans and biophysical conditions influence these communities. The high-resolution mapping products identified many unmapped features of interest, such as seamounts, banks, ridges, guyots, hydrothermal vents, and soft sediment abyssal communities. PIDSCI research efforts provided new understanding of deep-sea biological communities, and identifed areas of high abundance and diversity. Many of these communities of high abundance and diversity are within the prime crust zones that may be targeted for deep-sea mineral extraction in the near future. Data analyses are leading to new insights into taxonomy, habitat utilization, key drivers of biodiversity, ecological functions and connectivity, and impacts from various types of disturbance. Bathymetric syntheses at relevant scales have led to new fishery assessments critical to management of local deep-water bottomfish, and combined with new observations of deep coral occurences, led to an updata of precious coral essential fish habitat. New habitat suitability models continue to be refined using data and observations from ROV dives.

We have not completely answered any of our 2014 questions but have gained many new insights. Future research missions will need to rely less on extensive cruises and rely on more statistically-based limited transects and sampling. Data from such study designs can provide more quantitative information regarding taxonomy, connectivity, genetics, species diversity and distribution. We definitely need more in-situ measurements of current flow and other environmental parameters to more fully understand the conditions that lead to the colonization and development of mature assemblages of coral and sponge communities. We also need more rigorous models that would enable us to predict not just locations of deep-coral communities but estimate their vulnerability to disturbance. Data to improve these models must be collected at the appropriate temporal and spatial scales to enable both field researchers and modelers to parse key variables. Deep-sea mining is probably the most imminent threat to the deep-sea coral communities in the U.S. Pacific Islands, and managers would be well served if more information regarding deep-sea corals were forthcoming in the years before the DSCRTP funding rotation returns to the Pacific Islands. New partnerships, new scientists, and new funding will all be key to making this possible. Participants acknowledged that limited resources are available to address the wide geographic area of the Pacific Islands region. Consequently, a coordinated approach and targeted activities will be required in order to enhance our understanding of deep-sea corals and sponges' ecosystems of the region.

Priorities for future deepsea coral work in the US Pacific Islands

Many research and exploration gaps still exist. CAPSTONE only revealed the "tip of the iceberg," leaving many features and large geographic areas unexplored, especially outside the U.S. Exclusive Economic Zone (EEZ) and south of the Equator. Corals and sponges occur throughout the Pacific marine monuments, and quantitative exploratory surveys are needed to determine species compositions and distributions to answer management questions regarding protected areas and impacts of development and extraction of the substrate by marine mining. Working with partners and using a range of deep submergence assets exploration will be a key to any successful future deep-sea coral and sponge work in the U.S. Pacific Islands. Continuous process improvement of OER survey methodology is necessary to meet many statistically-sound science objectives along with outreach objectives. Development of new sampling protocols is necessary to provide insight into connectivity, taxonomy, and genetics. Protocols and tools are needed to collect a meaningful suite of environmental data (in-situ currents, light intensity, planktonic concentrations, etc.) that may influence biogeography, growth, and condition of deep-water communities. These data need to be collected across time as well as space (an expensive endeavor) to adequately incorporate them into habitat- and ecosystem-based management models needed by managers. Video and data extraction, analysis capability, and infrastructure developed at the University of Hawaii, as well as new automated image analysis capabilities using artificial intelligence require support to optimize resources during future surveys that utilize video as the main source of biological observations. In the past, progress on deep-sea coral research has been dependent on tying its relevance to fishery and protected species mandates (precious coral fishery, monk seal use of deep coral patches, subphotic fish habitats, black coral fishery). In the future, study of deep-water communities will likely focus on their relevance to the greater ocean ecosystem and how impending disturbances (mining, ocean acidification, climate change) will impact these ecosystems. Our understanding of FeMn crust communities is still rudimentary, and we have little understanding of potential impacts of FeMn mining. Many benthic communities (i.e., seamounts and soft sediments) remain under-sampled even though they may be critical to overall ecosystem function. Educating and training a new generation of deep-sea research scientists is essential to future progess. Continued development of strong partnerships will allow us to move to hypothesis-driven science within the aegis of exploration in order to better address the most critical resource questions of both science and management.

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Appendix 2. Combined Corals, Sponges, Associates CAPSTONE Observations

https://drive.google.com/file/d/1QHn-WJNpuH19QValfvCTKxlHJkDSpSX-/view