Deep-sea Coral Research and Technology Program: Pacific Islands Deep-sea Coral and Sponge 3-year Research Wrap-up Workshop May 23–24, 2018

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Background

The National Oceanic and Atmospheric Administration's (NOAA) Deep Sea Coral Research and Technology Program (DSCRTP) was established under Section 408 of the 2006 Magnuson-Stevens Reauthorization Act (MSRA, Public Law 109-479). 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 3-year exploration and research priorities plan for the Pacific Islands Region. From 2015 through 2017, the DSCRTP allocated resources to be used by the NOAA Pacific Island Fisheries Science Center (PIFSC) and partners to begin implementing priority research efforts. The PIFSC and DSCRTP sponsored a follow-up workshop in Honolulu, Hawaiʻi on May 23–24, 2018, after the 3-year program ended, to review its accomplishments and suggest improvements for future work. The objectives of this 2018 workshop were to (1) review major outcomes of the 3-year Pacific Islands Research Initiative that are completed and still in progress; (2) identify how the exploration and research results support improved scientific understanding of deep-water biogenic habitats in the Pacific Islands and current or future management information needs, particularly those of the Western Pacific Regional Fishery Management Council (WPRFMC) and the Pacific Islands Marine National Monuments; and (3) identify remaining research needs in the U.S. Pacific Islands region and make recommendations for future Deep Sea Coral Research and Technology Program's partnerships and fieldwork.

Wrap-up Workshop Overview

The NOAA Strategic Plan for Deep-sea Coral and Sponge Ecosystems (the Strategic Plan) identifies national-level goals, objectives, and approaches to guide NOAA's research, management, and international cooperative activities on deep-sea coral and sponge ecosystems for 2010 through 2019. The primary goal of the Strategic Plan is to improve the understanding, conservation, and management of deep-sea coral and sponge ecosystems. The Strategic Plan covers deep-sea coral and sponge ecosystems under the jurisdiction of the United States and international cooperation activities undertaken by the United States.

Section I of the Strategic Plan identifies the role of research in management, including NOAA's priorities and objectives for research and exploration of deep-sea coral ecosystems and anticipated products for each objective. The goal of NOAA's exploration and research on deep-sea coral and sponge ecosystems is to provide sound scientific information that will enable effective ecosystem-based management decisions. The DSCRTP provides funding on a rotational basis to each operating region and expects these funds to be leveraged with other resources to enable collaborative projects through four NOAA line offices to optimize the utility of the limited funding.

To further its mission, the DSCRPT funded efforts between 2015 and 2017 in the Pacific Islands region that included projects 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 analysis, 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 4000 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 brought together 30 researchers, managers, and subject-matter experts to examine the results, successes and challenges of the 3-year research effort; to discuss the management benefits that have accrued from the research; and to consider further partnerships, analyses, outreach, and field work needed in the coming years to sustain this effort after the rotational funding has ended.

Participants were asked to consider the following questions:

- What research questions have we answered?
- What have we learned about deep-sea corals and sponges, and their biophysical environments?
- What does it mean?
- What further analyses are needed to provide meaningful scientific, outreach, and management products?
- How can results best be used to support management?
- How will management benefit from this research?

- What efforts worked best in the Pacific Islands region?
- How can we maintain and further develop partnerships for deep-sea coral and sponge research work?
- What work can be continued and supported between 2018 and 2024, when the DSCRTP rotational funding will again be available to the region?

Wrap-up Workshop Details

The goal of the workshop was to (1) summarize major research outcomes, and identify work that is complete or still in progress; (2) discuss ways that the exploration and research results support improved scientific understanding of deep-water biogenic habitats in the Pacific Islands and current or future management information needs; and (3) identify remaining research needs in the U.S. Pacific Islands Region and to make recommendations for future Deep Sea Coral Research and Technology Program's partnerships and fieldwork. The workshop, which was organized by the Pacific Islands Fisheries Science Center (PIFSC) and NOAA's DSCRTP, was held in May 2018. Attendees included NOAA and other government agency scientists and managers, academic researchers, and others who participated in the 3-year research efforts. A complete list of workshop attendees can be found in Appendix A.

The workshop was held over the course of 2 days:

Day 1 presentations provided an overview of the DSCRTP-funded field research in the U.S. Pacific Islands region, with sessions covering Campaign to Address Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE), coral taxonomy, genetics, biogeography, depth distribution, environmental determinants, growth and recovery from disturbance. These presentations were followed by a group discussion that focused on the following questions:

- What are the strengths and weaknesses of CAPSTONE for scientific research and exploration?
- What research gaps remain?
- How could research and exploration be more cohesive and mutually beneficial regionally or through time with other programs within and outside NOAA?
- Which aspects of project and cruise reporting worked well, and which should be improved?

Day 2 presentations focused on products derived from existing and current data sets, predictive modeling efforts, management use of DSCRTP products, management priorities, and partnership maintenance and development. Day 2 presentations were followed by a group discussion that considered the following questions:

- What are the strengths and weaknesses of CAPSTONE for habitat protection and management?
- What kind of information could be gathered and produced to better inform resource management?
- How could we better incorporate deep-sea habitat issues into broader ecosystem-based management (EBM) or spatial management approaches?
- Which partnerships within CAPSTONE worked well, and which ones could be improved?

The complete agenda can be found in Appendix B.

Presentations

To set the context for the first day, presentations were given to provide an overview of the national program, the NOAA Pacific Islands area research priorities, and an extended presentation describing the accomplishments of the CAPSTONE program. CAPSTONE consumed a large share of the DSCRTP funding for the region, and provided a level of geographic and depth coverage that would not have been possible without the NOAA ship *Okeanos Explorer* (OE) and her remotely operated vehicle (ROV) the Deep Discoverer, and the NOAA Office of Ocean Exploration and Research (OER) funding contributions. These were followed by presentations that discussed research and exploration results, divided into four topic headings: biogeographic and genetic patterns, vertical distribution of corals and sponges, environmental factors influencing coral and sponge communities, and disturbance and recovery of coral communities.

Day 1 Presentations: Research and Exploration

U.S. Pacific Islands research – National Perspective of NOAA's Deep Sea Coral Research and Technology Program. (Tom Hourigan, NOAA DSCRTP)

Hourigan outlined the legal mandates, rotational funding, and cross-line office nature of the DSCRTP. He provided an overview of DSCRPT research and regional efforts, and stressed the need to prioritize research that will be relevant to management, and that would enable enhanced collaboration necessary for the program to be successful, especially in years between funding. He emphasized that data and products from all of the funded research could be found at the deep-sea coral data portal.[1]

Recap of 3-year research plans and activities for the Pacific Islands.
(Michael Parke, Pacific Islands Fisheries Science Center)

Parke reviewed major objectives of the 3-year initiative (listed above), and introduced speakers who would provide updates on the progress of research efforts. He posed the following questions for participants to consider for discussion during the meeting:

- Did our research and exploration improve our scientific understanding of deep-water habitats in the Pacific Islands?
- What products were generated to inform current or future management information needs, particularly those needed by the WPRFMC and the Pacific Islands Marine National Monuments?
- What remaining research needs to be conducted in the U.S. Pacific Islands region and are there partnerships that can be developed or enhanced that will facilitate future research in areas relevant to the DSCRPT?

[1] https://deepseacoraldata.noaa.gov/

Campaign to Address Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE) Summary. (Kelley Elliot, NOAA Office of Ocean Exploration and Research)

Elliot provided a recapitulation of the 3-year CAPSTONE expedition in the Pacific Islands, which enabled scientists to identify and map limited areas of deep-sea coral and sponge abundance and diversity, and determine their vertical distribution in the U.S. Pacific Islands, especially in the U.S. marine monuments and sanctuaries. She also highlighted the following accomplishments.

The NOAA Ship *Okeanos Explorer* (OE) spent 431 days at sea, mapped over 635,000 km^2, conducted 187 ROV dives at depths ranging from 250 to 6000 m, collected 333 primary biological (along with many still-uncounted commensal organisms) and 278 geological samples, actively engaged > 260 participating scientists, students and managers during ROV dives, and streamed > 16 million views of live video feeds of the expedition.

OER has made available expedition quality assured and quality controlled data sets including multi-beam, geophysical, oceanographic, and high-resolution videos through the National Centers for Environmental Information archives, and provided easy access to online visualization and data downloads through the OER Digital Atlas. Preserved biological samples are housed at the Smithsonian Invertebrate Zoology Collection, with a subset of certain samples also housed at Bishop Museum's Marine Invertebrate Collection. Small tissue samples were also provided to Northeastern University's Ocean Genome Legacy Center. All geological samples reside at Oregon State University's Marine Geology Repository.

CAPSTONE investigated the geologic history of Pacific seamounts, including potential relevance to plate tectonics and subduction zone biology and geology, and increased our understanding of deep-sea biogeographic patterns across the central and western Pacific. Finally, the OE missions enabled us to examine the biology and characterize seamounts in and around the prime crust zone (PCZ) for the first time. The PCZ is the area of the Pacific with the highest concentration of commercially valuable deep-sea minerals contained within a ferromanganese (FeMn) crust that precipitates onto rock in the deep ocean , and potentially a region where deep ocean mining will take place in the not-too-distant future.

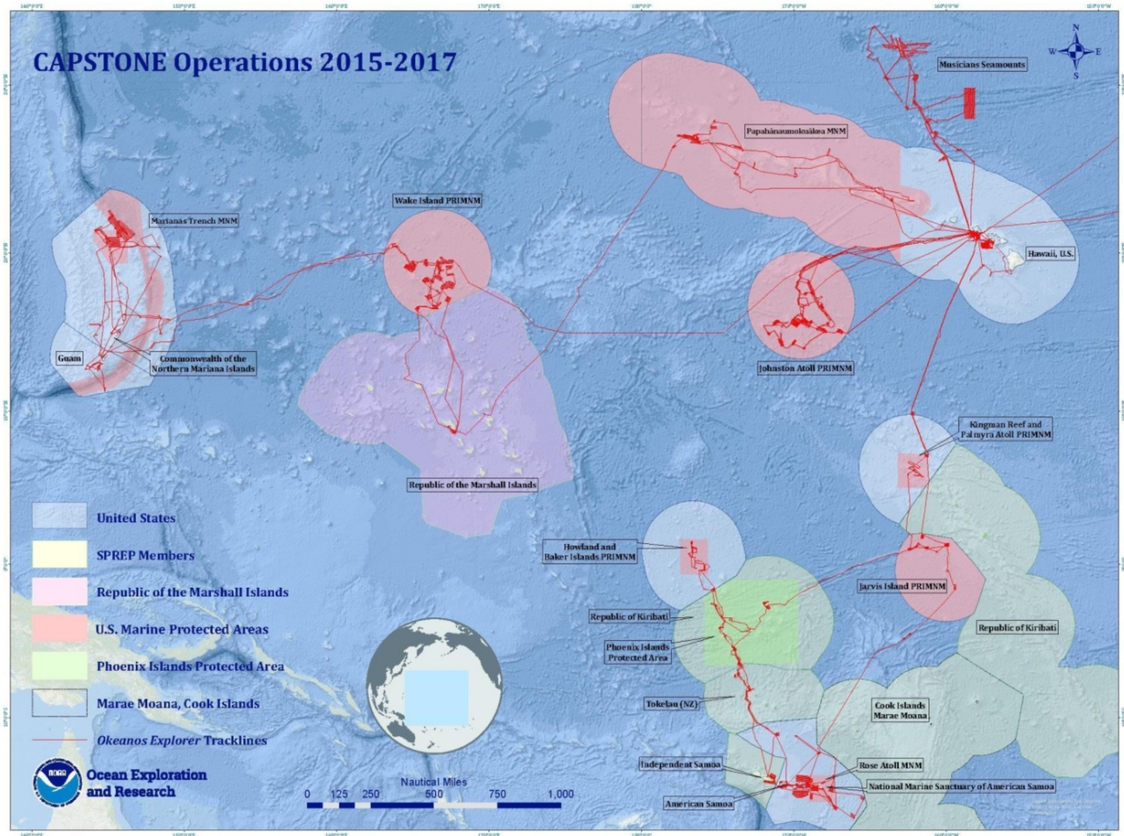

Figure 1. Extent of CAPSTONE operations in the Pacific Islands 2015–2017.

Population size structure of the shallow water black coral, *Antipathes griggi.*
(Anthony Montgomery, US Fish and Wildlife Service/ University of Hawaii)

Montgomery was first in a series of presentations that examined the population ecology, growth rates, genetics and distribution of corals in Hawaii and the Pacific. He and his team set up monitoring sites to sample and study growth and post-harvest recovery rates of scuba-accessible black coral populations in the main Hawaiian Islands (MHI). Preliminary data analyses indicate that population size structure was steadily shrinking from 1980 to 2010 in over 40 years of measurements, but more recent measurements indicate that more large corals are being observed. He attributed a portion of this change to less harvest pressure from the black coral industry. Montgomery and Robert Toonen from the Hawaii Institute of Marine Biology are also working to make genetic comparisons among black coral samples from various parts of the Hawaiian archipelago.

Black coral distribution and taxonomy.
(Daniel Wagner, NOAA Office of Ocean Exploration and Research)

Wagner presented results from scuba surveys of black coral populations in Hawaii and American Samoa designed to determine taxonomy and distribution of black corals. Between 2015 and 2016, he conducted dives at 86 sites on 15 islands or seamounts from Hawaii Island to Kure, and collected and analyzed >100 specimens. Using microscopy and morphological analyses, Wagner documented 6 different black coral species, along with 5 substantial range expansions, and confirmed that commercially viable populations of the two 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.

In American Samoa, at 12 sites offshore of Tutuila Island, in depths of 35–100 m, Wagner collected 35 black coral specimens and tentatively identified 12 species, 10 of which are possibly new records for Samoa. He still is working to confirm species-level identifications for these corals.

Biogeographic patterns in U.S. Pacific seamounts and guyots.
(Chris Kelley, University of Hawaii)

Using biological data extracted from video analyses and environmental parameters collected during the OE dives throughout the U.S. Pacific Islands, Kelley presented preliminary findings documenting coral and sponge distribution in the basin. He found significant differences in dissolved oxygen minima values and depths throughout the Pacific that are likely affecting basin-wide biogeographical patterns. His analyses showed that OE exploratory dives did not produce evenly nor randomly distributed samples with respect to either depth or region, and this needs to be taken into account when analyzing dive data for either biogeographic or depth zonation patterns. The OE dives on PCZ guyots provide the most comprehensive baseline in existence on communities that will likely be impacted by the FeMn crust mining industry, and therefore provide an invaluable data set for the future. PCZ guyot communities were dominated by corals and sponges, with both high- and low-density communities found throughout the PCZ. Community density decreased significantly below 2500 m. Most corals and sponges were observed in areas of FeMn-encrusted bedrock with low amounts of sedimentation. These areas will also be targeted for mining.

Biodiversity transitions in the deep Pacific Ocean with a focus on American Samoa and the Samoa Passage. (Santiago Herrera, Lehigh University)

Herrera worked with baseline data collected during OE missions in American Samoa and poorly 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 4000 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 Samoa region appear to be largely structured by depth. In addition, the exploration of an active volcano, Vailulu'u seamount, revealed recent eruptive activity over the last 20 years. The timing of these eruptions is associated with an apparent pattern of ecological succession of the benthic communities living in the crater. 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.

Vertical distribution patterns from limited observations in the U.S. Pacific Islands.
(Chris Kelley, University of Hawaii)

Kelley shared his preliminary analyses of the vertical distributions of corals found during research expeditions conducted by the OE during 2015 and 2016. He emphasized that the video sampling was not random, nor equitably spaced at the range of depths, so cautioned listeners to consider these limitations when drawing conclusions. More than half of sampling was conducted between the depths of 1200 and 2400 m. The largest numbers of coralliids colonies were found between 200–600 and 1400–1800 m depth, with a few thousand fewer colonies found between 1800 and 2200 m. Coralliid colony counts per hour of video were highest in the 1400–1800 m depth range. Gorgonian colony counts per survey hour were highest in the 1400–1800 m depths, with fewer found in the 1800–2200 m depths. Colony counts were considerable less in other depth ranges. Antipatharian colony counts per survey hour were also highest in the 1400–1800 m depth range. The highest Hexactinellida colony counts per survey hour were found in the 1400–1800 m depth range, with smaller peaks at 1800–2200 m. Hexactinellida colonies were also the most common ones found below 3000 m depth.

Bathymetric and backscatter data synthesis for Hawaii and Pacific Islands: Geologic substrate mapping of U.S. Pacific Islands. (John Smith, University of Hawaii)

Smith explained the value of multi-beam mapping for both geological and biological exploration. He outlined his efforts to synthesize 30 years of multi-beam bathymetry and backscatter data to develop integrated geologic and bathymetry maps for the Pacific Islands. With 50-m multi-beam and 60-m backscatter map synthesis products already in wide use throughout the Hawaii marine community, Smith highlighted his recent work on 5-m resolution bathymetry and backscatter syntheses, and showed how human processing is necessary to supplement machine algorithms during reclassification of data sets from a different sonar systems or ships. He shared his work to create bathymetry and backscatter syntheses, as well as geological substrate maps for Johnston Atoll and Papahānaumokuākea Marine National Monument, and his intent to create a similar geologic substrate map for the main Hawaiian Islands.

Flow characteristics of deep sea coral and sponge communities.
(Frank Parrish and Thomas Oliver, NOAA Pacific Islands Fisheries Science Center)

Parrish and Oliver used submersibles to place 18 instruments on the seafloor to measure and monitor the flow direction, speed, and tidal spectra of the water movement through patches of deep-sea corals at 3 topographically different sites. Over periods ranging from 7 to 30 months, the instruments measured similar average flow rates at 2 of the coral patches (12.7–13.6 cm/s) and a much lower rate at the third (4.5 cm/s). Tidal extremes pushed max flow speeds to as high as 95.3 cm/s, 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/m traveled) than the patch where the max flow was recorded (11 taxa and 0.20 colonies/m traveled). The data from the placement of multiple instruments within a patch showed variability consistent with topographic influences on flow rates (e.g., ridges vs. sheltered substrate). Study sites with higher average flow showed coral community patterns with higher populations of *Acanthogorgia* sp., Coralliidae, *Lepidisis olapa*, Primnoidae, and *Thouarella hilgendorfi*, while 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 2 high-flow sites. Comparisons of the tidal spectra at the 3 locations show obvious differences among the 3 patches and tidal flows are critical to understanding colonization patterns of deep coral and sponge communities.

Geochemistry of deep sea corals in Hawaii. (Sam Kahng, Hawaii Pacific University)
Working with samples of marine carbonates and different Coralliidae and Isididae species collected off 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 1 year (2017) to explore and model environmental versus vital effects for these species. Kahng stressed that this geochemical work is just beginning and will take a few years, and is beginning with Mg/Ca ratios correlating to in situ temperature at different depths.

Field Logistics and Preliminary Results of Exploratory Surveys to Examine Recovery of Seamount Precious Coral Beds From Trawling Disturbance and Fisheries Impacts and Recovery of Vulnerable Marine Ecosytem (VME) Taxa on the northwestern Hawaiian Ridge and Emperor Seamount Chain Seamounts.
(R. Brendan Roark, Texas A&M University and Amy Baco-Taylor, Florida State University)
Roark and Baco-Taylor discussed the National Science Foundation (NSF)-funded research that they conducted in the Northwestern Hawaiian Islands (NWHI) and Hawaii-Emperor Seamounts. They looked primarily at 3 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. They wanted to answer the following questions:

1. How does the species composition, abundance, and diversity of megafauna compare between the seamounts of the three treatment types?
2. How long after the cessation of trawling did it take for precious corals to recolonize? Is colonization continuous? If not continuous, how frequent is colonization? Are populations observed at “still trawled” and “recovering” sites remnant populations or new colonizers?

3. Genetic Structure – What is (are) the source population(s) of the colonizing corals? Are all cohorts present at a given location from the same source populations?

Using the Hawai‘i Undersea Research Laboratory (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 km. They collected voucher specimens of dominant fauna, > 800 genetic samples of Coralliidae, and > 300 aging-paleo samples. They found evidence of massive fishing impacts even in areas that were no longer fished. They observed localized *Corallium* recovery or regeneration that was most likely from remnant populations. Where there was clear fishing damage and recovery, the dominant megafauna were soft corals suggesting the ecosystem has moved to an alternate state than one where precious corals with hard skeletons might have dominated.

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 under-saturated water. They believe that factors contributing to reef presence or absence include chlorophyll, high speed currents bringing nutrients, and other environmental parameters.

Roark and Baco-Taylor also plan to develop a colony height-to-age and growth-rate curves using direct measurements of height, width and diameter along with radiocarbon dating, and use these results to determine the various size and age classes of *Corallium* across multiple seamounts in the NWHI.

Precious coral settlement patterns on Hawai`i lava flows.
(Sam Kahng, presenting for Meagan Putts (University of Hawaii)

Putts' research was focused on the length of time it takes for a deep-sea precious coral community to recover from disturbance. Although Putts used natural disturbances (geologically dated lava flows) in her study, results from her work should be applicable to human induced disturbances such as bottom trawling, precious coral harvesting, or development activities. Her main conclusions identified distinct patterns of deep-water precious coral species succession, with Coralliidae being early colonizers, followed by the bamboo corals (Isididae) and antipatharians, with parasitic gold coral (zoantharia) the last to recruit into the disturbed areas. She established a timeline for precious coral community development, calculating that it takes approximately 150 yr for Coralliidae in Hawaii to achieve mature size structure, and greater than >2,000 yr for the gold coral (*Kulamanamana haumeaae*) to reach harvestable size. Her observations during this research led her to conclude that commercial stocks of Hawaiian precious corals are probably much larger than previous estimates. Although she was able to correlate measures of bathymetric position index (BPI) with coral presence and abundance, she was not able to confirm strong correlations with other terrain properties and coral presence and abundance as found by other benthic modelers.

Group Discussion Day 1

Workshop participants were asked to consider the following questions related to deep-sea coral and sponge exploration and research in the Pacific Islands:

- What do you think were the strengths and weaknesses of CAPSTONE for scientific research?
- What do you think were the strengths and weaknesses of CAPSTONE for exploration?
- What important research and/or exploration gaps still exist in the Pacific Islands region after CAPSTONE?
- How could we conduct more cohesive and mutually beneficial research and exploration regionally or through time with other programs within and outside NOAA?
- Which aspects of project/cruise reporting worked well, and which should be improved?

Scientific strengths/weaknesses:

One of the greatest strengths of CAPSTONE was the ability to conduct high-resolution mapping and ROV operations throughout the central and western Pacific U.S. Marine Monuments and in some international areas to gather relevant baseline data on deep-sea coral and sponge communities. This broad geographic scope was not envisioned at the original 2014 planning meeting of the Pacific Islands deep-sea coral and sponge initiative. CAPSTONE proved to be particularly adept at forging partnerships among different line agencies and including both science and management agencies in defining priority targets. The willingness of the CAPSTONE team to enhance their sampling capability and modify their operating protocols to accommodate different scientific requests was commendable. The strong and geographically diverse team of principal investigators that the program was able to recruit (volunteers for the most part) and maintain throughout the 3-year effort demonstrated the value of the high-resolution telepresence. These scientific partnerships and more general outreach work brought together many experts and led to new collaborations. The telepresence also raised awareness of the thriving deep-sea biological communities in our national marine monuments and attracted new people to the field of deep-ocean science.

CAPSTONE significantly increased our basic understanding of the geology and biology of the seafloor in the Pacific Islands areas where little to no data previously existed, and generated information for managers and the scientific community to guide follow-on research. The multi-beam mapping products alone will serve many different constituencies for years to come. CAPSTONE was able to augment and support existing research projects even though its normal operations are not intended to support research. CAPSTONE was able to provide data to begin to answer broad questions related to biogeography of deep-sea corals, depth distributions between 250 and 6000 m, likely locations for high-density deep-sea coral and sponge communities, and presence of biological communities on ferromanganese crusts. These data will be valuable to provide semi-quantitative and qualitative tests to hypotheses identified a posteriori, and should inform our efforts to predict and model deep-sea coral habitats. CAPSTONE provided the opportunity to address many of the priorities identified in the 2014 deep-sea coral meeting, work that may not have been accomplished due to uncertainties regarding research vessel availability during the last 3 years. Chris Kelley and his team have done a remarkable job extracting (and making publicly available) relevant data from the superb video footage and still imagery, as well as the ambient environmental data that were collected. These data, along with the biological and geological samples collected during the campaign will be valuable sources of scientific information for years to come, and it is critical to keep this data extraction team funded in the future. Finally, although not directly related to CAPSTONE, Brendan Roark and Amy Baco-Taylor have produced some remarkable work on recovery from disturbance and community succession.

Participants identified some common weaknesses in the CAPSTONE program. The design of CAPSTONE was primarily focused on exploration, not on testing specific scientific hypotheses. The science value of the effort was limited due to the non-systematic and non-quantitative survey protocols and image or specimen data collection methods (i.e., non-systematic video transects along with limited sampling). The OE field methodology only provided a snapshot of certain depth ranges, and scientific survey methods were not employed. Depth variation between different ROV dive sites precludes any meaningful quantitative analysis. Operational rules limited the ROV to a linear transect distance of 800 to 1000 m. Videographers spent an excessive amount of time on certain animals, and inadequate time on others, often zooming in to obtain close-ups of portions of organisms without obtaining good, full-frame images of the entire animals (especially for fishes). Specimen collection or lack thereof, was a major complaint. The lack of specimen collection often prevented definitive identifications of species. However, collecting specimens takes a lot of time at the expense of completing planned survey tracks. In most ROV dives, the shallow end-point was not reached because of the time spent collecting specimens, including rocks, and obtaining close-up views. The challenge of collecting multiple specimens while completing dive transects is not easily solved. The major challenges related to morphological taxonomy of corals and sponges could not be met with videos, no matter how fine the resolution. The only real way to definitively address distribution or biogeographic questions is through DNA sequencing and collected specimens. Relying on video identifications alone can drastically over-represent species ranges and underrepresent species diversity, and 2 or 3 specimens per dive are not adequate for these studies. The program represented a huge investment of money and resources, and it is unlikely that we will return to these remote areas any time soon, so it seemed wasteful that so few specimens were collected when we had the opportunity. One suggestion to deal with these issues would be to initially survey a site using normal protocols, then return to the best features of that site on the next day for systematic surveys and sampling. Some expressed concern over the huge expenditures for exploration rather than science, and that money that was spent on CAPSTONE could have been allocated to produce better science and more publications using more traditional vessels on instruments (e.g., HURL and its PISCES submersibles).

Exploration strengths/weaknesses:

Major strengths of the CAPSTONE exploration mission included the incredible geographic and depth ranges that the expedition was able to cover, exploring many places that have had little or no deep-sea investigations. The multi-year commitment by OER and DSCSRP, the carefully cultivated partnerships with NOAA NMFS and the National Ocean Service (NOS) National Marine Sanctuaries and National Marine Monuments programs, the real-time inclusion of renowned scientists, and the public inclusiveness of the project through telepresence all contributed to the success of and excitement generated by the project. The skill and obvious enthusiasm of the videographers, ROV operators, and science leads made for great outreach opportunities. The generation of high-resolution bathymetry and backscatter maps will facilitate building partnerships at the local, NOAA, national and international level. The high-resolution videos inspire public interest and next-generation scientists, and facilitate outreach communication about the importance and value of ocean exploration and deep-sea habitats. These videos, maps, and samples inform questions on geological origins, biological distribution, presence, absence, and vertical zonation in unexplored areas. Any information about these previously unexplored areas will assist managers responsible for the areas.

Weaknesses were primarily related to the lack of scientific rigor that went into survey and sampling design. While exploration is the key to expanding our understanding of the deep ocean, exploration can be done in a quantitative manner over large areas in ways that produce much better quantitative analyses, science results, and resource efficiencies. Many participants believed that the duration and survey distance of the dives were unnecessarily short due to nature of OE staffing and telepresence demands. While telepresence is great for engaging a broader audience, it doesn't really add to productivity, though many identifications and sample collection decisions were facilitated through telepresence participants. Compared to recent research using submersibles in the NWHI seamounts, which covered as much as 14,000-m distance in one day, exploration productivity could be enhanced, perhaps using edited highlights as opposed to live streaming.

What important research and/or exploration gaps still exist in the Pacific Islands region after CAPSTONE?

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. Now that we know that corals and sponges occur throughout the Pacific Monuments, we need quantitative exploratory surveys to determine species compositions and distribution, and to answer management questions regarding protected areas and impacts of development and extraction of the substrate by marine mining. To ensure taxonomic certainty and provide insight into connectivity, significant numbers of samples must be collected and genetically analyzed. Protocols and tools are needed to collect a meaningful suite of environmental data (currents, light intensity, planktonic concentrations, etc.) that may influence both 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. Work in the depth ranges important for commercial fisheries was minimal, and identification of many fish taxa to the species level was not possible. Our understanding of FeMn crust communities is still rudimentary, and much work remains relative to identifying 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.

Large amounts of data (especially video) are available but have yet to be extracted into usable information. With more data being generated, and the use of autonomous vehicles becoming more widespread, we need to maintain current analysis capacity and develop new automated techniques. This is true for both video analysis and bathymetry and backscatter data processing, products which often serve as the base maps for habitat modeling efforts. Other environmental data and data derived from samples (taxonomy, genetics) need to be made available, as soon as feasible, and catalogued in easily accessible formats. Products derived from the voluminous data should be tailored for use by managers and ecologists, with analysis priority going to data that can help to answer questions related to connectivity, species distribution biogeographically and in depth zones, habitat condition, vulnerability, and other management priorities. An effective way to deal with the plethora of data may be to prioritize analyses and data-mining efforts around testable hypotheses. Funding will be an ongoing challenge, as will be the loss of institutional knowledge with many pending retirements in the deep-sea research community. We need to develop effective recruitment tools and training opportunities for new scientists and graduate students, and optimize ways to share information and analysis methods. Perhaps the greatest need is to develop strong partnerships that allow us to move to hypothesis-driven science within the aegis of exploration to better address the most critical resource management questions of both science and management.

How could we conduct more cohesive and mutually beneficial research and exploration regionally or through time with other programs within and outside NOAA?

The OE maintains excellent videographic and broadcasting capability aboard, but perhaps too many for the duration of operations per day, driving up the cost. Having more slots available for funded science types would take some of the load off the science leads. The expense of large ocean research vessels can be prohibitive to follow-up research. Perhaps we can establish a consortium of organizations and vessels that will collaboratively identify regional priorities and incorporate those into multi-year and multi-platform operations. Cooperative work in the Pacific may be a challenge due to potential loss of the HURL submarines. NSF funding demands proposals with well-defined hypotheses that can be tested during a research effort. Preliminary analysis of existing data, even those collected in a non-systematic manner, could provide particular hypotheses with clear focus on areas or features of particular interest to scientists and managers. Biogeographic analysis of image data available through the DSCRTP Deep-Sea Coral database may be one potential area of research. Funding support of academic scientists and NOAA researchers for extraction and analyses of existing data may offer a more realistic option for the Pacific Islands region than the creation of a new consortium.

Which aspects of project/cruise reporting worked well, and which should be improved?

Chris Kelley and his team should be commended for making the huge effort to successfully extract meaningful data from the videos and still imagery in a reasonable amount of time. Chris also made the critical linkage between the navigation files and all of the environmental data. The dive summaries and cruise reports varied in both quality and timeliness depending on chief scientist. These could be useful archival tools so should be readily accessible and standardized. Perhaps if they were published as NOAA tech memos, the reports would be more prompt and usable. Environmental data that were collected should be available in one place, and easily located and downloaded. Report requirements involving collaboration between OER and DSCRTP should not be duplicative, and should be standardized. Some of the transitions between data-logging and chat-room software and protocols were confusing. While SeaSCribe is useful for initial IDs, it is not optimal for OER needs. Final data products should be quality-controlled, readily accessible, and formatted in a way that both the science and management community can easily incorporate into their respective analyses. Perhaps the biggest weakness is the lack of dedicated funding for the science community to continue the momentum and work-up the CAPSTONE data and samples.

Day 2 Presentations: Partnerships, Management, and Future Research

Perspectives on CAPSTONE and future Pacific Islands collaboration.
(Kelley Elliot, NOAA OER)

Elliot stressed that even though the OE had left the Pacific Islands region, other vessels were scheduled to be operating in the area over the next few years. The Ocean Exploration trust and E/V *Nautilus* would be in Hawaii in 2018, conducting mapping work and ROV dives on seamounts near the Murray Fracture Zone, in the Papahānaumokuākea MNM, and on some other poorly explored, enigmatic seamounts.

John Smith, using the Schmidt Ocean Institute R/V *Falkor*, will be conducting an expedition to investigate the bathyal biogeography of the Emperor Seamounts in late 2018. All of these efforts encourage participation by shore-side scientists.

Progress and products from HURL and Okeanos expeditions.
(Chris Kelley, University of Hawaii)

Kelley explained that HURL maintains an unknown number of biological and geological samples (in the thousands). He led participants through the HURL video-processing protocols and database creation. His team at the University of Hawaiʻi has made progress correcting, extracting, and formatting HURL database records, adding substrates to 30,000 HURL submitted to DSCRTP, and supplementing the HURL animal guide. Improvement of positioning data remains a challenge. He also detailed both HURL transect data and OE video data processing protocols. He outlined the myriad data collected during OE ROV dives, including biological and geological samples, CTD, salinity, tracking, still images, high-definition video, multi-beam swaths, and how these data have all been geocoded and made available to interested researchers.

He highlighted the *Okeanos Explorer* Animal Guide[2], which currently has 3,025 images, and after 2017 images are incorporated, will have ~1,500 more. Detailed annotations of dive video data extraction are also available, with 123 of 177 dives completed (more than 315,000 animals recorded). DSCRTP and OER requested regional reports for the various areas where CAPSTONE dives took place. Reports are being prepared for the following regions: Papahānaumokuākea Marine National Monument, main Hawaiian Islands, Geologist Seamounts, Musicians Seamounts, Johnston Atoll Unit of the Pacific Remote Islands Marine National Monument (PRIMNM), Wake Atoll Unit of the PRIMNM, Marianas and the Mariana Trench Marine National Monument, American Samoa, Tokelau Seamounts, Phoenix Islands Protected Area (PIPA), and remaining units of PRIMNM.

Predictive modeling for deep-sea corals in the Hawaiian Islands.
(Bryan Costa and Matt Poti, NOAA National Centers for Coastal Ocean Science [NCCOS])

Costa and Poti used existing deep-sea coral observations from the HURL and national deep-sea coral databases to create spatially explicit predictive models for 18 deep-sea coral groups, and identify unexplored areas likely to contain suitable habitat for these taxa. While initially created for the Bureau of Ocean Energy Management (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 (*Corallium*), 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 that they were useful for guiding targeted exploration efforts by the PIFSC in the MHI.

Western Pacific Regional Fishery Management Council research priorities related to deepwater corals. (Joshua DeMello, WPRFMC)

DeMello outlined the general research priorities for precious corals of the WPRFMC that are called for in the Magnuson-Stevens Reauthorization Act, including better stock assessments, determining critical life-history parameters, modeling ecosystem function, and developing metrics for socio-economic impacts. More specific priorities include setting annual catch limits for pink, red, bamboo, and gold corals, extending or making permanent the moratorium on gold coral harvests, determining a maximum sustainable yield for all the precious corals, and reexamining the definitions of corals beds, essential fish habitats (EFH), and habitat areas of particular concern (HAPC) for all deep-water precious corals. Our understanding of black corals, which commercially occur primarily in waters shallower than 120 m, has advanced a great deal in the last two decades, providing a better understanding of taxonomy, growth, reproduction, recruitment,

[2] http://oceanexplorer.noaa.gov/okeanos/animal_guide/animal_guide.html

distribution, and fishing pressure. This led to development of management measures based on size limits, and area restrictions. Future management efforts will be based on eventual harvest interest and pressure from the fishery, because the fishery is moribund and limited at the present time.

Use of 3-year research program data to update precious corals EFH.
(Michael Parke, NOAA PIFSC)

Parke used existing (HURL data) and new data (OE data) to map the locations of each precious coral species observation in Hawaii. He synthesized life history research, environmental conditions, bathymetry data, and backscatter data to determine habitat characteristics and rationale for boundary determinations and bed definitions. The description of habitat characteristics and geographic extent (bed boundaries) combine to make a complete EFH designation. Habitat characteristics for the benthic phase of deep-water precious corals *Pleurocorallium secundum*, *Hemicorallium laauense*, and *Acanella* spp. are natural, stable, hard substrates between the 200 and 600 m isobaths in areas with higher current velocities, low sedimentation, and where precious coral and associated communities are clustered. EFH for the benthic phase of *Kulamanamana haumeaae* is the tissue or skeleton of bamboo coral colonies, particularly *Acanella* spp. are the preferred hosts of the parasitic *K. haumeaae* in depths between 200 and 600 m. Higher current velocities mean the accelerated or localized, enhanced flows necessary to sweep away sediment and increase the flux of organic matter. While the particular velocity requirements are unknown, recent work suggests a range of 0.3–0.85 m/s may be an ideal range.

Parke and the plan team developed deep-water precious coral bed boundaries or confirmed existing EFH boundaries and locations using known locations, bathymetry, and hardness data to finalize bed shapes and depth contours. While existing beds were defined using a central coordinate and radius, new bed boundaries were drawn in whatever shape most closely matched the geophysical characteristics of the proposed bed.

Statistically sound estimates of distribution, abundance, and condition of precious corals throughout the MHI are needed to further refine EFH and HAPC. Targeted surveys of areas that meet the depth and hardness criteria of the preferred habitat could provide very accurate estimates. We still do not understand the environmental conditions necessary for precious coral settlement, growth, and reproduction. The same surveys used to determine abundance and distribution could collect these environmental data as well. We also lack quantitative measures of growth and productivity, and definitive taxonomies for many managed species.

Papahānaumokuākea Monument priorities (Jonathan Martinez, NOAA NOS)

Martinez summarized the history and current management regime of the Papahānuamokuākea National Marine Monument, and provided a brief summary of the research conducted in the area. He outlined the current and future research and management priorities for the monument. These included high resolution multi-beam and backscatter mapping to enable characterization of the features such as seamounts, banks, ridges, guyots, abyssal plains, and determination of geologic composition and origin. Managers also need data that will help them understand the biological communities that inhabit these features, habitat utilization rates, biodiversity levels, ecosystem functionality, and impacts of climate change. They are most interested in synthesized information and predictive habitat models that can be used to enhance management and educational efforts. Finally, he highlighted some of the maritime heritage resources that are found in the monument, and stressed their interest in developing partnerships with anyone who wishes to conduct science in the monument.

Pacific Marine National Monument management and research priorities
(Malia Chow, NOAA NOS)

Chow introduced the participants to the Pacific Islands Regional Office (PIRO) Marine Monuments program staff and mission. They develop and implement monument management plans and activities, with federal, state, and territorial partners, to meet directives of the Presidential Proclamations and Federal Mandates such as MSRA, Endangered Species Act (ESA), and Marine Mammal Protection Act (MMPA). They collaborate with PIFSC and other researchers to obtain priority ecosystem monitoring data, fisheries information, and science needs especially for key monument features to inform management decisions.

They operate under relatively strict timelines for development of management plans and scientific and public reviews of those plans.

With regard to deep-sea corals, the management focus is to characterize features within the Monuments (banks, seamounts, ridges, hydrothermal vents), to identify areas of high abundance or biodiversity hotspots, to understand the drivers behind deep-sea coral distribution and abundance, to understand the connectivity of deep-water corals between and within habitat types, and to characterize the linkages between deep-sea corals and ecosystems. The types of information managers need include habitat interpolations that utilize available geophysical data such as depth, substrate, and slope to predict where deep-sea corals and sponges are likely to be found, and in what types and quantities. They need maps at scales that are biologically relevant for resource management, and they need models to identify important environmental factors to forecast which corals and sponges are most at risk from changing ocean conditions (e.g., climate change).

Deep Sea Coral Research and Technology Program perspectives on partnerships, interim and future deep coral research in the Pacific Islands.
(Thomas Hourigan, NOAA Office of Habitat Conservation [OHC])

Hourigan provided a funding cycle timeline to participants, and stressed that although Hawaii will not be a part of the main funding cycle again until 2024, there are targeted small project funding opportunities for data mining and analysis, coral genetics, fieldwork, modelling, and others. He stressed the utility and availability of the national deep coral database, and the need to partner with other research institutes such as Schmidt Ocean Institute and the Ocean Exploration Trust. He also expressed a desire to see all the regions take advantage of multiagency initiatives, and funding opportunities from NSF and OER. BOEM in particular offers opportunities for research or management partnerships in U.S. waters for science-related projects to offshore renewable energy siting, potential deep-sea mining, biodiversity determinations, and potential pharmaceutical extraction.

PIFSC deep coral research priorities and bridging the gap between now and cyclical national funding. (Frank Parrish, NOAA PIFSC)

Parrish stated that this workshop marks the end of the 3-year DSCRTP investment in the Pacific Islands Region. By working with partners and using a range of deep submergence assets, exploration was expanded into new areas throughout the Pacific. An important product was an update of the OER methodology in meeting its science and outreach objectives that involved the cross section of the community and provided the metadata, imagery, transcription data, and samples efficiently to accessible repositories. In large part this was achieved by building on methods, staff and infrastructure of the Hawaii Undersea Research Laboratory that supported work in the region for the 3 decades prior. Initially this was funded by NOAA/National Undersea Research Program followed by the NOAA Ocean Exploration Initiative and at the end persisted intermittently on a series of small awards and production contracts. Throughout this time, 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 habitat, black coral fishery) which have largely been addressed or are no longer a high priority. A new model will be essential for future study of deep-sea corals that is tailored to the emerging interests of the day. The DSCRTP has increased the profile of deep-sea corals to the scientific and management communities, and to the public, and has a defined deep-coral management mandate (although largely unfunded). It is not clear how directed process studies in deep-sea coral ecosystems might continue in the future but they should be considered when the *Okeanos Explorer* or *Nautilus* are working in the region. Until dedicated deep-sea coral funds are again directed at the Pacific Islands Region the focus of work should be on analyzing and publishing results from the last 3 years using the available information to model the probable location of corals, and identify areas for future exploration or coral patches for future process studies

Maintaining a deep water data extraction and synthesis capability through partnerships and inter-funding cycles (Chris Kelley, University of Hawaii)

Kelley was particularly concerned about maintaining an experienced post-cruise products team to continue to provide quality data to DSCRTP after this funding cycle is finished. Custom imagery for the expansion of the OER animal guide provides an invaluable photographic reference to researchers and video annotators. He suggested we need one or more sources of continuous funding for deep-sea video annotation, data processing, data synthesis, and image guide production. Current funding from UH and DSCRTP is set to run out by 2019. A great deal of HURL video data has yet to be annotated, and many new ships and instruments will be generating vast streams of new imagery data. Kelley is working hard (even in retirement) to identify additional sources of funding for deep-sea video annotation, data processing, data synthesis, and image guide production. He warned participants that developing a lab with the current expertise is no easy feat.

Discussion

Partnerships and Management

Workshop participants were asked to consider the following questions related to the relevance of exploration & research to management, as well as the value and future of research partnerships:

- What do you think were the strengths and weaknesses of the information gathered by CAPSTONE for habitat protection and management?
- What kind of information could be gathered or produced to better inform resource management?
- How could we better incorporate deep-sea habitat issues into broader ecosystem-based management or spatial management approaches?
- Which partnerships within CAPSTONE worked well, and which could be improved?

What do you think were the strengths and weaknesses of the information gathered by CAPSTONE for habitat protection and management?

The obvious strength of CAPSTONE is the video collection, along with its high-resolution mapping and ancillary environmental data. These data, even before annotation and final quality assurance and quality control, can provide managers with an initial sense of diversity and productivity of previously unexplored regions. After further analyses, these data may allow managers to make resource allocation decisions related to future research. Unfortunately, the videos and samples were not collected in a statistically rigorous manner that would facilitate quantitative analyses regarding diversity, distribution, and connectivity. Videos themselves have limited value without samples to confirm taxonomic discrepancies. The Kelley lab at UH produces high-quality annotations of corals and sponges, and could expand their annotations to include other invertebrates and fishes. The collaboration between CAPSTONE and DSCRTP made these annotations possible, and lack of funding for annotations may be a problem for other video collections in the future. The loss of institutional capacity due to funding lapses may also have a negative impact on annotation. One glaring weakness related to habitat protection is the live broadcast of video in areas without any protection. The deep-water focus of the dives at depths where mining may take place in the future precluded work in habitats of more immediate concern to managers, i.e., bottom fish and precious corals.

What kind of information could be gathered and produced to better inform resource management?

The most important data needed to inform resource management are habitat-based productivity, growth rate, reproduction, diversity, and distribution data. Limited distribution and diversity data have been extracted from existing video, but barring unlimited ship time and dive days, life history data are unlikely to be available, so more focus should be placed on biogeography and productivity of key features and sites that have already been shown to have important biological communities. Further analyses of video and environmental data beyond mere annotations is required. Publications would demonstrate the value of the data to the larger scientific community, and perhaps generate more interest from outside researchers to explore the data. More focus should be placed on shallower habitats (200–600 m), especially in areas where extraction of living resources is ongoing. The most useful management products are those that are presented in a spatial context and that provide descriptions of functional relationships. Meaningful site characterizations and comparisons among sites and regions that provide estimates of productivity, diversity, and vulnerability are of great value to managers.

How could we better incorporate deep-sea habitat issues into broader ecosystem-based management or spatial management approaches?

Dive plans and survey tracks must be designed with statistical rigor to create baseline information that is meaningfully comparable for management purposes. Dive survey tracks must be longer to provide adequate information for each survey site.

Which partnerships within CAPSTONE worked well, and which could be improved?

The partnerships among the NOAA line agencies (OER, NMFS, NOS) worked particularly well. Although it can be challenging to meet everyone's needs on every dive and expedition, OER did a fine job of communicating and soliciting input from all interested agencies. Bringing resource managers into the planning and exploration process ensured that some of the information collected during the expedition directly assisted their management needs. Partnerships with a diverse scientific community were also remarkable, with strong participation of scientists from various disciplines throughout the entire campaign. The use of social media as an outreach tool increased the visibility of the campaign and contributed to the scientific literacy of the public. The partnerships developed with HURL and UH were also productive and exemplary.

Partnership with the Monuments program may have been enhanced with better guidance and input on the types of final data products that would be most useful to managers. Perhaps future partnerships could be developed that would facilitate standardization of derived mapping products from the multi-beam data, as would synthesis of annotations and other environmental data into easily usable management products. The partnerships established for sample repositories need to be improved for the future. The Smithsonian is a logical and appropriate repository for biological samples; however, it would be desirable to enable a system to track the fate of those samples after handed to the Smithsonian (e.g., updated database of specimen identification, linked to data derived from specimen identification). The Smithsonian may also be the most appropriate partner to serve as a genetic repository, with its extensive collections and expertise. The partnership with Ocean Genome Legacy (OGL) should be reconsidered given the uneven quality of OGL DNA "preservation" kits, and the DNA purified by OGL, which make meaningful analysis difficult. OGL charges a hefty fee to any researcher that wishes to access this material. Better partnerships could be cultivated with academic institutions that could provide more qualified and experienced lead scientists for the cruises, especially if more funding were made competitively available for entities outside NOAA. Future deep coral biogeographic research and habitat modeling efforts would certainly be enhanced through academic partnerships.

Concluding Thoughts about the 3-Year Pacific Islands Deep-Coral Research Initiative

The Pacific Islands Deep-Sea Coral and Sponge Research Initiative Wrap-up brought together more than 30 researchers and resource managers to summarize the results of the 3-year Pacific Islands Deep Sea Coral and Sponge research initiative, as well as try to develop some guidance for future research activities in the region. After 2 days of preliminary research presentations and discussions, workshop participants identified the successes of the 3-year initiative and challenges that face the region over the next few years without dedicated funding from the national deep coral and sponge program.

> Participants agreed that the CAPSTONE mission provided a very rich set of data that can be mined and analyzed for years to come. 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? We still do not know the predominant factors that influence deep coral distribution, though Frank Parrish, Brendan Roark, Amy Baco-Taylor and Chris Kelley have suggested that source populations, currents, oxygen, particulates, and chlorophyll begun to offer some clues about the environmental factors affecting distribution. The geographic scope of the CAPSTONE mission, combined with Daniel Wagner's taxonomic research on black corals, has enabled us to make some early inferences regarding the biogeographic patterns at the Pacific basin scale. Amy Baco-Taylor, Meagan Putts, and Tony Montgomery have all contributed to our understanding of the time it takes deep-coral communities to recover from disturbance. Chris Kelley and his UH colleagues have provided a tremendous service by extracting the data from long-archived HURL data sets. Although not definitive by any means, and subject to the taxonomic limitations of the surveys, we have preliminary indications that some corals can thrive even beyond 4000-m depth, but that most seem to prefer depths shallower than 2400 m.

We have not definitively answered any of our 2014 questions but have gained some 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. More in-situ measurements of current flow and other environmental parameters are necessary. We also need more rigorous models that would enable us to predict not just locations of deep-coral communities, but to 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 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 to enhance our understanding of deep-sea corals and sponges ecosystems of the region.

Appendix A: Participants List

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Appendix B: Workshop Agenda

Deep Sea Coral Research and Technology Program: Pacific Islands Deep-sea Coral and Sponge 3-year Research Wrap-up Workshop May 23–24, 2018 Honolulu, Hawaii

Workshop objectives:

1. Review major outcomes of the 3-year Initiative – completed and in-progress
2. Identify how the exploration and research results support the following themes:
   - Improved scientific understanding of deep-water biogenic habitats in the Pacific Islands
   - Current or future management information needs, particularly by the Western Pacific Regional Fishery Management Council and the region's Marine National Monuments
3. Identify remaining research needs in the U.S. Pacific Islands region and recommendations for the Deep Sea Coral Research and Technology Program's partnerships and fieldwork

Wednesday, May 23:

	SETTING THE STAGE	
8:30	**Welcome**	Michael Parke
8:35	**U.S. Pacific Islands research – National Perspective of NOAA's Deep Sea Coral Research and Technology Program**	Tom Hourigan
	Recap of 3-year research plan and introduction of speakers. The plan identified priority questions we will discuss in the workshop	Michael Parke
	Campaign to Address Pacific monument Science, Technology, and Ocean Needs (CAPSTONE) Summary	Kelley Elliot
	RESEARCH AND EXPLORATION	
Question 1	**Biogeographic/Genetic Patterns**	
9:15	**Population size structure of the shallow water black coral, *Antipathes griggi***	Anthony Montgomery
	Black coral distribution and taxonomy	Daniel Wagner
	Biogeographic patterns in U.S. Pacific seamounts and guyots	Chris Kelley
	Biodiversity transitions in the deep Pacific Ocean with a focus on American Samoa and the Samoa Passage	Santiago Herrera
10:45	Break	
Question 2	**Vertical Distribution of Corals and Sponges**	
	Vertical distribution patterns from limited observations in the U.S. Pacific Islands	Chris Kelley
11:35	***Group Discussion** – Questions 1 & 2*	
12:00	Lunch	
Question 3	**Environmental Factors**	

1:00	**Bathymetric and backscatter data synthesis for Hawaii and Pacific Islands. Geologic substrate mapping of U.S. Pacific Islands**	John Smith
	Flow characteristics of deep sea coral and sponge communities	Frank Parrish
	Marine carbonate Boron stable isotope depth gradient and calibration and *Corallium* stable isotope temperature calibration	Sam Kahng
2:15	Break	
Question 4	**Disturbance and Recovery**	
2:30	**Field Logistics and Preliminary Results of Exploratory Surveys to Examine Recovery of Seamount Precious Coral Beds From Trawling Disturbance**	Brendan Roark
	Fisheries Impacts and Recovery of VME Taxa on the northwestern Hawaiian Ridge and Emperor Seamount Chain Seamounts	Amy Baco
	Precious coral settlement patterns on Hawai`i lava flows	Sam Kahng (for Meagan Putts)
3:30	***Group Discussion** – Question 3 & 4*	
4:00	***Group Discussion*** – *Strengths and weaknesses of CAPSTONE for scientific research and exploration* – *Gaps remaining* – *How could research and exploration be more cohesive and mutually beneficial regionally or through time with other programs within and outside NOAA?* – *Which aspects of project/cruise reporting worked well, and which should be improved?*	
5:00	**Close Day 1**	Michael Parke
6:00	Group Dinner	

Thursday, May 24:

	PARTNERSHIPS, MANAGEMENT, AND FUTURE RESEARCH	
8:30	**NOAA Office of Exploration & Research – Perspectives on CAPSTONE and future Pacific Islands collaboration**	Kelley Elliott
	Progress and products from HURL and Okeanos expeditions	Chris Kelley
	Predictive modeling for deep-sea corals in the Hawaiian Islands	Bryan Costa and Matt Poti
	Western Pacific Fishery Management Council research priorities related to deepwater corals	Joshua DeMello
10:10	Coffee break	
10:25	**Use of 3-year research program data to update precious corals EFH**	Michael Parke
	Papahānaumokuākea Monument priorities	Jon Martinez
	Pacific Marine National Monument management/research priorities	Malia Chow
11:40	***Group discussion*** – *Partnerships and Management*	
12:00	Lunch	
	LOOKING AHEAD	
1:15	**Deep Sea Coral Research and Technology Program perspectives on partnerships, interim and future deep coral research in the Pacific Islands**	Tom Hourigan
	PIFSC deep coral research priorities and bridging the gap between now and cyclical national funding	Frank Parrish
	Maintaining a deep water data extraction and synthesis capability through partnerships and inter-funding cycles	Chris Kelley

2:30	***Group discussion*** – *Strengths and weaknesses of CAPSTONE for habitat protection and management* – *What kind of information could be gathered/produced to better inform resource management?* – *How could we better incorporate deep-sea habitat issues into broader EBM or spatial management approaches?* – *Which partnerships within CAPSTONE worked well, and which could be improved?*	
4:00	**Review of action items and wrap-up**	Michael Parke
4:30	**Close Day 2**	

Appendix C: Acronyms and Abbreviations

AUV – autonomous underwater vehicle
BOEM – Bureau of Ocean Energy Management
BPI – bathymetric position index
CAPSTONE – Campaign to Address Pacific monument Science, Technology, and Ocean Needs
DSCRTP – NOAA Deep Sea Coral Research and Technology Program
EBM – ecosystem-based management
EEZ – Exclusive Economic Zone
EFH – essential fish habitat
ESA – Endangered Species Act (ESA)
FeMn – Ferromanganese (in reference to the crust that the target of potential marine mining)
HAPC – habitat areas of particular concern
HURL – Hawai'i Undersea Research Laboratory
MHI – main Hawaiian Islands
MMPA – Marine Mammal Protection Act
MNM – Marine National Monument
MSRA – Magnuson-Stevens Reauthorization Act
NCCOS – NOAA National Centers for Coastal Ocean Science
NMFS – NOAA National Marine Fisheries Service
NOAA – National Oceanic and Atmospheric Administration
NOS – NOAA National Ocean Service
NSF – National Science Foundation
NWHI – Northwestern Hawaiian Islands
OE – NOAA Ship *Okeanos Explorer*
OER – NOAA Office of Ocean Exploration and Research
OGL – Ocean Genomic Legacy
OHC – NOAA Office of Habitat Conservation
PCZ – prime crust zone
PICSI – [No name found for this acronym]
PIFSC – NOAA NMFS Pacific Island Fisheries Science Center
PIPA – Phoenix Islands Protected Area
PIRO – NOAA NMFS Pacific Islands Regional Office
PRIMNM – Pacific Remote Islands Marine National Monument
ROV – remotely-operated vehicle
UH – The University of Hawai'i
VME – Vulnerable Marine Ecosystem
WPRFMC – Western Pacific Regional Fishery Management Council