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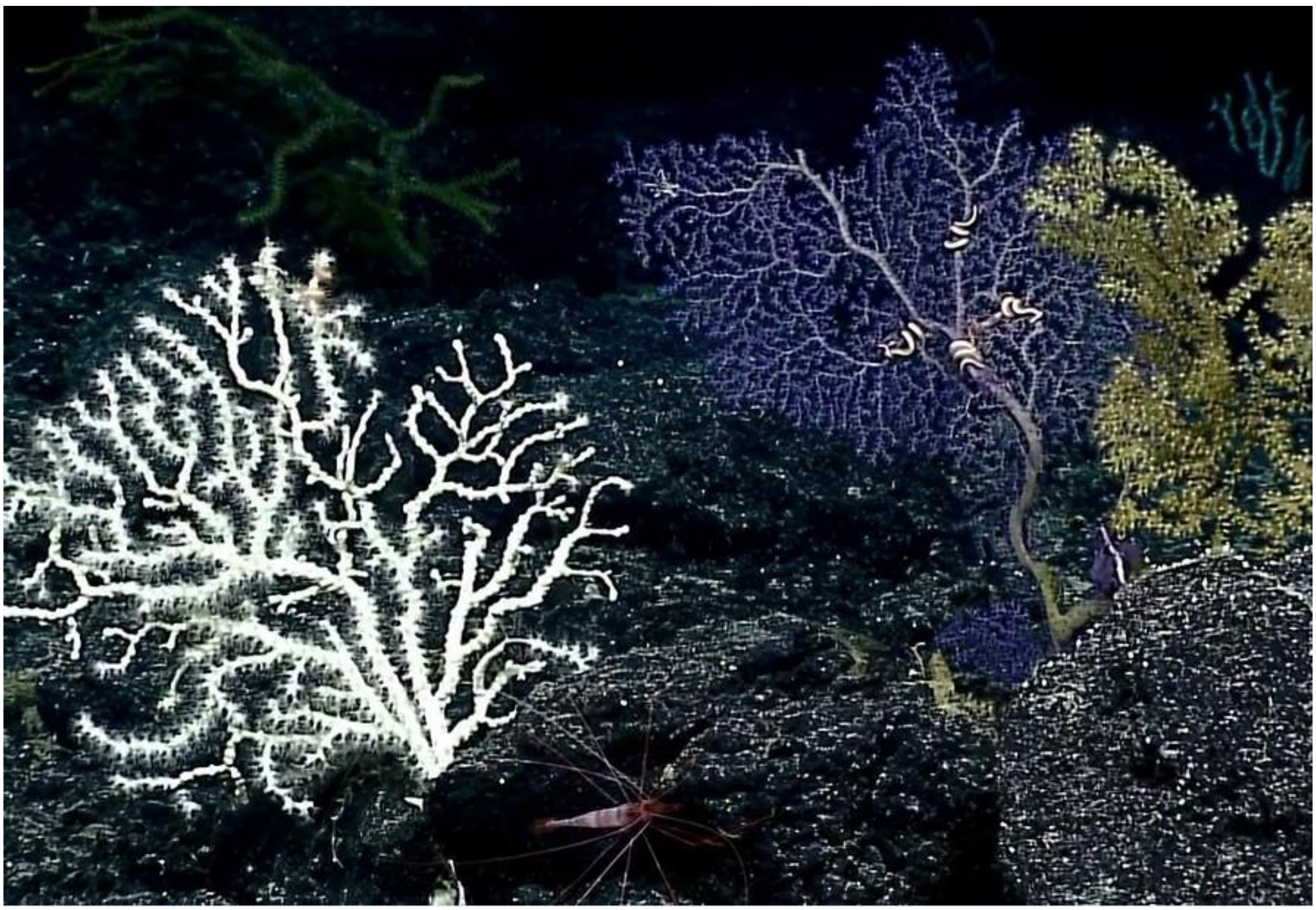

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Application of the Coastal and Marine Ecological Classification Standard (CMECS) to Deep-Sea Benthic Surveys in the Northeast Pacific: Lessons from Field Tests in 2015

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EXECUTIVE SUMMARY

Introduction

The Coastal and Marine Ecological Classification Standard (CMECS) is a comprehensive, standard terminology published in 2014. The standard is intended to unify habitat classification efforts, in order to allow for broader integration and comparison of data. The standard is well-developed, and has been implemented in some regions, but CMECS not been tested extensively in the deep sea. NOAA has set a milestone to adopt recommended best practices and standards, such as CMECS, within NOAA's Integrated Ocean and Coastal Mapping Program, since 2013 (NOC 2013), so there is a timely need for guidance directed toward the deep-sea research community about how to apply this standardized methodology.

This report summarizes the findings from a short-term research project that engaged field teams during three deep-sea benthic surveys in the US Pacific in 2015, including telepresence-enabled cruises in Southern California and Hawaii. The researchers conducted post-cruise analyses to process images from surveys aboard NOAA Ship *Okeanos Explorer*, *E/V Nautilus* from Ocean Exploration Trust (OET), and *R/V Shearwater* from the NOAA Office of National Marine Sanctuaries (NMS). Thirty-two remotely operated vehicle (ROV) dives and more than 6,400 still images were analyzed using a simple CMECS annotation.

The report considered three of the four CMECS components — geoform, water column, and substrate. The biotic component was not reported here, this was reserved for separate study. Biotic units can be derived from species diversity and abundance but the quantification of these categories is evolving and needs refinement.

Outcomes

- CMECS geoform and water column components can be incorporated by benthic survey field teams with little modification to standard operating procedures.
- Parameters such as geo-position, depth, temperature, salinity, and oxygen are routinely collected by submersibles. These values can be reported in standard documents (cruise reports) and converted to CMECS categories through "crosswalk" procedures.
- The CMECS water column component uses categorical definitions based on measured values. These categories need consideration, because researchers in different regions recognize similar categories with different ranges of values.
- Minimum and maximum values of depth, temperature, salinity, and oxygen can be reported for the on-bottom period of each dive on a cruise. These may be classified into CMECS depth zones, temperature categories, salinity regimes, and oxygen regimes.
- The CMECS substrate component is most applicable at a spatial resolution < 10 square meters.
- Geological annotation should be modified to include both induration and vertical relief in order to be most useful for habitat characterization and modeling.
- The CMECS substrate component may need to be modified to include sediment types, rock types, and primary and secondary relationships, to support seafloor habitat characterization.
- Geological expertise is necessary for reliable interpretation of substrate from images. For example, sand and mud are not easy to distinguish in images.

Recommendations

- The upper level geoform scale is highly relevant to the deep-sea exploration enterprise. Geoforms are part of the exploration vernacular (e.g., seamount, canyon), and may be used to characterize dives, but not necessarily cruises.
- The geoform component may be integrated into dive logs and dive summaries at NOAA Office of Ocean Exploration and Research (OER), Ocean Exploration Trust (OET), and other federally-funded deep-sea benthic survey teams.
- The water column component may be reported as a standard table showing maximum and minimum values for depth, oxygen, temperature and salinity for each dive. Computer code should be developed to "crosswalk" this table into various CMECS categories.
- The present categorical definitions for water column need to be reviewed, and possibly augmented based on feedback/comments received from surveys of other observers, in order to be more comprehensive and regionally representative.
- Substrate values should be incorporated into live annotation protocols aboard telepresence cruises. Periodic data entry is recommended, preferably by a trained geologist. Primary geology, secondary geology, and relief should be recorded.
- The recommended periodic interval for data entry ranges from every 5 or 10 seconds to every 5 minutes, depending on regional standards, mission objectives, and staff available.
- Some substrate categories need new modifiers. Add "volcanic" or "volcanic rock" as a modifier to substrate descriptions in the CMECS catalog. It would also be helpful to add subcomponents such as "pillow basalt".

In summary, this study found that CMECS is useful and applicable for deep-sea exploration. The Federal Geographic Data Committee (FGDC) standard can be incorporated into deep-sea research efforts with minimal cost and impact. Some modifications may be required to make the CMECS standard useful to deep-sea surveys, and some new annotations may be required to make deep-sea surveys compliant with CMECS. However, aspects of the CMECS standard can feasibly be met with relatively minor modifications to standard operating procedures.

The team of the NOAA ship *Okeanos Explorer* will pilot test a new annotation software application, SeaScribe, in 2017. The software will be customized for video annotation in a real-time setting via telepresence by participating scientists around the world. The NOAA Office of Exploration and Research (OER) is working to incorporate CMECS into the annotation schema to the maximum extent practicable. OER shorthand annotation codes may become obsolete as this new annotation software is developed. However, a controlled vocabulary is still recommended to standardize data entry and make it more efficient.

CMECS could be employed as an organizational schema for sorting and filtering a geo-database of deep-sea submersible dives. The US deep-sea exploration community should seek to develop a new spatial database that uses CMECS categories to tag deep-sea dives from a large number of institutions. A geodatabase of CMECS attributed dives would allow for useful and interesting data queries (e.g. show all dives from Pacific seamounts, show dives in anoxic depths, or dives from Atlantic canyons) to promote deep-sea science and discovery.

1.0 ABSTRACT

A standard terminology for visual benthic surveys is useful and necessary for seafloor mapping, habitat classification, and habitat suitability modeling of the deep sea. The Coastal and Marine Ecological Classification Standard (CMECS) is a comprehensive, standardized terminology published in 2014. The standard is well-developed but has not been tested extensively in the deep sea. NOAA has set a milestone to adopt recommended best practices and standards, such as CMECS, within NOAA's Integrated Ocean and Coastal Mapping Program, since 2013 (NOC 2013), so there is a timely need for guidance directed toward to the deep-sea research community about how to use this standard method. To this end, the project described in this report engaged ocean going field teams during three deep-sea benthic surveys in the Pacific Ocean in 2015, including telepresence-enabled cruises in Hawaii and Southern California. Post-cruise analyses processed and categorized images from these surveys. Thirty-two remotely operated vehicle (ROV) dives and more than 6,400 still images were analyzed using a simple CMECS annotation. The primary outcome of the study was the discovery that CMECS geoform and water column components can be captured by field teams with little modification to standard procedures. Parameters such as depth, temperature, salinity, and oxygen are routinely collected by ROV and these can easily be converted to CMECS categories if minimum and maximum values are reported in dive summary tables and image annotations. The CMECS substrate component needs fine spatial resolution to be useful to seafloor characterization and modeling. Geological annotation of images should include induration and relief at a minimum to be useful for habitat suitability modeling. Sediment types, rock types, and primary and secondary relationships are useful for habitat characterization. Geological expertise was necessary for reliable habitat interpretation from images. Some inconsistencies were identified between CMECS and established regional regimes in the Pacific Ocean. For example, the entire California deep margin has very low oxygen levels and needs a finer categorization scheme than the Atlantic. The field tests in this study showed that CMECS can be useful and effective for deep-sea benthic surveys. CMECS helps to organize the deep-sea benthic community and represents a logical underpinning for a unified searchable geodatabase of deep-sea explorations at some point in the future.

2.0 INTRODUCTION

Habitat is the natural environment of an organism. It is analogous to an ecosystem, which includes both the biotic and abiotic components of the environment. Habitat mapping is a major priority for NOAA because it supports efforts to conserve or protect sensitive resources and essential fish habitat in the US Exclusive Economic Zone (EEZ). Deep-sea habitat is particularly challenging to assess because most observations are from still or video images of a small area with a limited field of view and few biological samples are collected. Modern survey techniques use advanced technologies like ROVs and autonomous underwater vehicles (AUVs) to bring cameras close to the seafloor with high operational precision. The vehicles can be used to collect visual observations over large areas. In addition to imagery, these platforms collect sediment and tissue samples. They also can be equipped with environmental sensors that record everything from temperature to fluorescence. These types of data can be better integrated with data from other ships and ROVs, and with other types of seafloor observations, if standards are applied so data can be shared and integrated.

There are a number of seafloor classification schemes in use around the world, and several with potential to support deep-sea studies. For example, the Collaborative and Annotation Tools for Analysis of Marine Imagery and Video (CATAMI) system for annotating benthic substrates and biota, was promulgated in Australia in 2015 and is used by various organizations, including government, industry, and academic institutions (Althaus et al. 2015). It focuses on classifying biota and habitat within individual images and, therefore, does not include terminology for large-scale components such as geoform or water column. The European Nature Information System (EUNIS) is a habitat classification system that was developed specifically for European seas and contains region-specific components (Galparsoro et al. 2012). This may limit its utility outside of European waters.

In the United States, the Federal Geographic Data Committee (FGDC) has endorsed CMECS as a way to incorporate multiple aspects of the environment at a wide range of observation scales (FGDC 2012). To date, CMECS has not yet been used extensively for deep-sea exploration, nor has it been reconciled against the needs of the research scientists. The aim of the present study was to determine the utility of CMECS to classify benthic deep-sea habitats from geo-referenced surveys and images. The field tests focused on the geoform, water column, and substrate components of the CMECS system. The study did not pursue the biotic component of CMECS, which warrants separate consideration because of the complexity and depth of the subject.

2.1 Background on the Coastal and Marine Ecological Classification Standard (CMECS)

The CMECS catalog was endorsed by the FGDC to offer a standard format and common terminology for communication among investigators (FGDC 2012). It incorporates several commonly used classification methodologies (FGDC 1996b, 2008) and was developed in recognition that over 60 different coastal and benthic classification systems have been used globally (Diaz et al. 2004). Most of these systems are designed for a specific scale, observation methodology, or focus on only one aspect of the environment (e.g. substrate). As a result, data integration, over larger geographies or between individual data sets has been difficult. CMECS was designed to address these limitations by incorporating all aspects of the environment relevant to biota, in a framework that is neutral in scale and works across technologies. CMECS can be applied to deep-sea sediment grabs or to satellite oceanographic data. CMECS can also add value to individual studies where data of disparate type and scale need to be analyzed together.

During pilot testing of CMECS version 2012, the draft standard was successfully applied to sediment grab samples in Mississippi Sound, Mississippi where CMECS substrate units were translated, or “crosswalked” from data classified using the Wentworth system (Wentworth 1922). The grain size thresholds in Wentworth were directly imported into CMECS substrate unit definitions because of their wide use among the marine geology community rather than adopting a soil-based approach to sediments. The Wentworth scale (Appendix A, Table A1) is based on grain size of sediment gravel (2-4,096 millimeters [mm]), sand (0.0625-2 mm), silt (0.0039-0.0625 mm), and mud (<0.00006-0.0039 mm). The scale is not entirely applicable to visual surveys because fine grain sizes cannot be determined in images, even when a pair of lasers is present for scale. Larger grain sizes of gravel (cobble, boulder) can be determined more easily. Often, both of these situations are present in a single image.

Of particular relevance to deep-sea coral observations are projects where CMECS has been applied to underwater video and still imagery. Several additional studies have been conducted using CMECS for seafloor sampling in the Northeast. This includes the NOAA Office for Ocean Exploration and Research (OER) applying CMECS to ROV data collected by the *Okeanos Explorer* as part of its Exploring Atlantic Canyons and Seamounts 2014 project (NOAA 2015a).

The Massachusetts Office of Coastal Zone Management's Seafloor and Habitat Mapping Program has been collecting sediment and benthic grab samples along with seafloor imagery since 2010 to understand the distribution and diversity of the state's seafloor habitats. The infauna (small sediment-dwelling organisms) observation data are being cataloged and attributed using CMECS biotic units (Mass. EEA 2015).

More recently CMECS was used to attribute field observations collected in Humboldt Bay and San Francisco Bay, California, to support and validate shallow-water benthic mapping from aerial imagery. The native data in these cases consisted of a mix of hand-held oblique photos in the intertidal zone and underwater video obtained from towed or drop cameras in subtidal areas.

2.2 The Hierarchical Structure of CMECS

The CMECS classification structure consists of several elements, including two settings, biogeographic and aquatic, and four main components, water column, geoform, biotic, and substrate. The system also contains over 30 modifiers (FGDC 2012). Each of these elements can be classified and mapped separately from one another. Within each component is a hierarchical structure, with increasing granularity of detail in the lowest units. This allows the user to apply the appropriate unit based on the information available. Besides a logical framework, the system provides descriptive definitions for pelagic and topographic features of the marine environment within each category.

The **water column component** consists of subcomponents for vertical layering: temperature, salinity, hydroforms, and biogeochemical features. It is the most spatially and temporally variable of the components; therefore, it includes a wide variety of modifiers for each subcomponent. It is intended to be applied for specific, individual observations as well as regional and large-scale processes. Although the component is called "water column", many of the units pertain to the benthic realm. For deep-sea (>50 meters [m]) benthic habitat observations, the water column layer will usually be one of the marine oceanic layers with appropriate depth modifiers and specific units such as oxygen regimes, temperature, salinity, and chlorophyll zones. An example would be, "marine oceanic mesobenthic, cool, euhaline layer." Some of the CMECS water column terms applicable to the deep sea are as follows: - oxygen minimum zone, oxycline, bathybenthic, Ekman downwelling and upwelling, deep convection, and deep circulation.

The **geoform component** is used to describe major structural and geomorphic features. It is intended for a variety of scales, allowing users to choose the scale best suited to their needs. This component contains most of the features in Greene et al. (2007) (Appendix A) and adds a few more. The four subcomponents, tectonic setting, physiographic province, large (level 1) geoforms (>1 square kilometer [km^2]), and small (level 2) geoforms (<1 km^2) — have an influence on the communities associated with them by providing structure and shaping water and energy flows (FGDC 2012). Abyssal plain, submarine canyon, authigenic carbonate outcrop, pinnacle seamount, and scarp/wall are typical geoform units attributable to the deep sea.

The **substrate component** includes geologic, biogenic, and anthropogenically originated materials. It is hierarchical, with particle size and substrate mix defining the unit used, modified from Wentworth (1922) (Appendix A). The main substrate classes are rock, unconsolidated mineral, and fine unconsolidated material. Substrate groups and subgroups include various rock types such as bedrock, mud, sand, gravel, and coral rubble, among others. All of these substrates are applicable to deep-sea coral habitats.

The **biotic component** describes benthic and floating or suspended biota, as well as biological composition. This component is hierarchical, containing settings, classes, subclasses, groups, and communities. Some of the units available are zooplankton, reef biota, floating plants and macroalgae, and faunal beds. Specific examples of benthic organisms are black coral colonized deepwater/coldwater reef, mobile crustaceans on soft sediments, and bacterial mat/film.

Figure 1 below shows the various elements of the CMECS framework. Each element can be applied independently or integrated with others to identify biotopes, which are unique landscape units with characteristic biotic and abiotic constituents.

Figure 1. This graphic illustrates the multiple elements of the CMECS system.

2.3 Deep-Sea Programs Within NOAA That May Benefit from CMECS

Several different programs and offices within NOAA are interested in deep-water (>50 m) habitat characterization, and all these would benefit from a standard approach and terminology to habitat classification. NOAA's Office of Ocean Exploration and Research, Office of Coast Survey, Pacific Marine Environmental Laboratory, National Marine Sanctuaries, and National Centers for Coastal Ocean Science are some of the NOAA offices that support and conduct deep-water field surveys. They use multibeam echosounders to produce seafloor maps, CTD (conductivity, temperature, depth) rosettes and sensors to characterize water column chemistry, and autonomous and remotely operated vehicles to conduct visual benthic surveys throughout the extensive U.S. EEZ.

NOAA's Office of Ocean Exploration and Research (OER) is dedicated to exploring the unknown ocean. OER provides the partnership, coordination, funding, staff, tools, and expertise needed to develop exploration missions that deliver rigorous, systematic observations and documentation of biological, chemical, physical, geological, and archaeological aspects of the ocean. The scale of observations range from hundreds of square kilometers mapped by multibeam to less than 1 meter in visual observations collected by submersibles and sensors.

NOAA's Office of Coast Survey (OCS) provides navigation products and services to ensure safe maritime activities, identify areas of environmental interest, and assist in simulation of impact events throughout U.S. coastal waters. NOAA's National Centers for Coastal Ocean Science (NCCOS) produces habitat characterization maps derived from topography and acoustic reflectance (backscatter) to inform monitoring and research programs. The Pacific Marine Environmental Laboratory (PMEL) surveys hydrothermal vents and chemosynthetic ecosystems to assess earth-ocean interactions. All these maps and surveys are most useful and interoperable when classified in a standard way.

NOAA's Deep-Sea Coral Research and Technology Program (DSCRTP) was authorized by the Magnuson-Stevens Act (MSA) in 2007 with a mandate to map and conduct research on deep-sea coral habitats, and provide this information to regional fishery management councils. Deep-sea coral and sponge communities provide essential habitat for fishes and invertebrates and create complex ecosystems that sustain marine biodiversity (Lumsden et al. 2007, Tittensor et al. 2009, NOAA 2010). This report does not address the biotic component because the subject warrants its own investigation and development process. Instead, the report seeks to apply and incorporate CMECS to the environmental data collected during field survey operations.

The 2010 NOAA Strategic Plan for Deep-Sea Coral and Sponge Ecosystems identified a very particular need to locate and characterize deep-sea coral and sponge ecosystems to better understand their biodiversity and ecology (NOAA, 2010). The NOAA Strategic Plan recognized that benthic surveys are limited in scope and extent, and that predictive models are necessary to fill gaps in our surveys to inform scientists and managers of areas where deep-sea corals are likely to be present. Habitat suitability models combine information on the presence and absence of corals with environmental parameters to ascertain correlations among abundance, habitat, and water column characteristics. The key points are that environmental data need to be standardized and discoverable in order to produce the best habitat suitability models, and that these models benefit from consistent habitat classification terminology to aid discovery. NOAA agencies engage in a cycle of exploration, analysis, characterization, modeling, verification, and re-exploration to make this possible (Fig. 2).

There are two major challenges to habitat suitability modeling for deep-sea corals. First is the lack of geo-referenced data regarding the location, abundance, and condition of these habitats (Tittensor et al. 2009, Bryan and Metaxas 2007, Davies and Guinotte 2011, Guinotte and Davies 2014, Tissot et al. 2006, NOAA 2010 and 2014). Second is the lack of a common terminology among scientists to characterize coral assemblages and describe their habitat (sensu Greene et al. 1999 and 2007, Hourigan et al. 2015). CMECS intends to promote and define this common terminology for both shallow and deep-sea ecosystems.

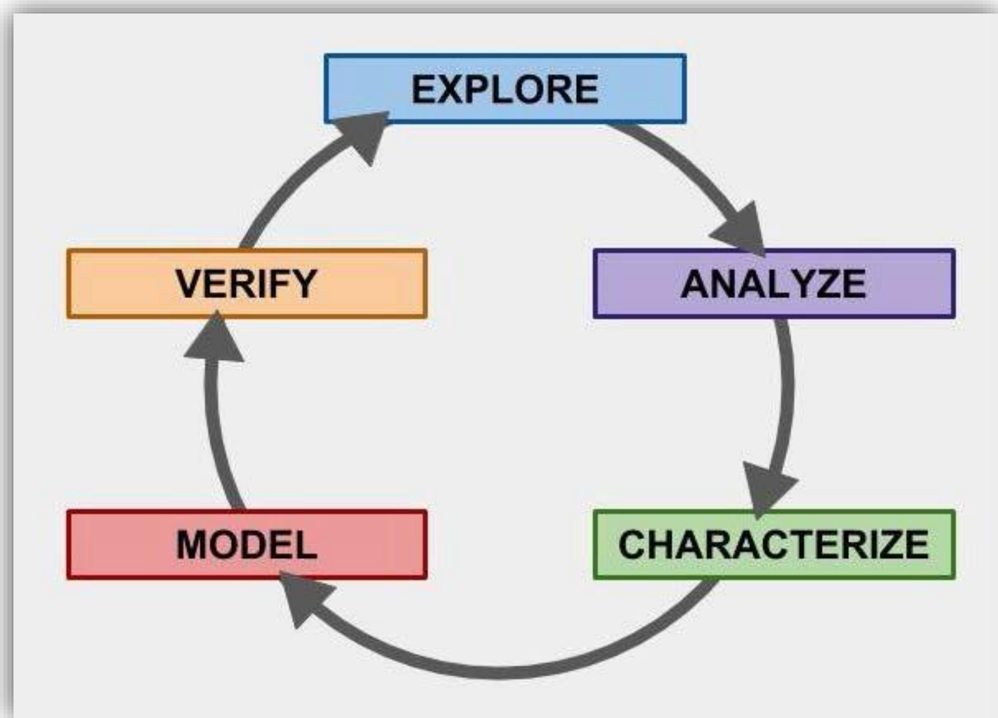

Figure 2. A graphic showing the cycle of exploration, analysis, characterization, modeling, verification, and re-exploration in which NOAA agencies are engaged.

The environmental factors that are known to predict deep-sea coral habitat include depth, substrate type, slope, topographic complexity, temperature, currents, aragonite saturation state, and organic carbon particulate (Guinotte et al. 2016). Although the importance of these factors varies by taxa, substrate type is commonly recognized as a powerful predictor. From a geological perspective, both induration (hardness) and vertical relief are important (Bryan and Metaxas 2007, Guinotte and Davies 2014, Dartnell et al. 2014, Tittensor et al. 2009), although this information is missing from many habitat suitability models (Etnoyer and Morgan 2007). The CMECS "substrate" component is therefore highly relevant to deep-sea characterization. Currents are also recognized as important (Genin et al. 1986, Bryan and Metaxas 2006, 2007), but these are difficult to model in the deep sea and have rarely been included until recently (Huff et al. 2013). Of the aforementioned environmental factors, only aragonite saturation state and organic carbon particulate are missing from the CMECS structure. The CMECS water column component is therefore also relevant to development of the next generation habitat suitability models.

2.4 The Need for a Pilot Application of CMECS to Deep-Sea Habitats

CMECS provides a standardized terminology that can record and provide habitat data from field exploration to any database, so there is a clear niche for this classification system to fill in the visual identification and prediction of deep-sea coral habitat. It has the potential to unify the currently existing and varied methods for habitat and substrate classification. However, there is a long history of annotation to consider and annotations may occur in real-time, so trials to test the feasibility and usefulness of incorporating CMECS are necessary.

A detailed timeline and review of geological characterization strategies used in the Northeast Pacific since 1999 is provided in Appendix A. While all are useful for their studies, only some aspects are interchangeable. A standardized, comprehensive characterization system could theoretically be implemented but such characterization methodology has not yet been widely adopted by the scientific community (FGDC 2012, Greene et al. 2007). CMECS incorporates existing standards and commonly used systems to the greatest degree possible. In addition, comparisons of similar terminology between these systems, called crosswalks, have been developed for previously established “legacy” data.

Benthic ecologists and geologists are encouraged to incorporate CMECS into their project designs in a way that maximizes project resources, meets project goals and yet also supports the need for better data integration.

NOAA has set a milestone to adopt recommended best practices and standards, such as CMECS, within NOAA's Integrated Ocean and Coastal Mapping Program, since 2013 (NOC 2013), so there is a timely need for guidance directed toward the deep-sea research community about how to use this standardized methodology. This study was undertaken to implement and understand the application of CMECS substrate, geoform, and water column components to deep-sea coral research. To this end, the project described in this report engaged field teams during three deep-sea benthic surveys in the Pacific in 2015, including telepresence-enabled cruises, and conducted post-cruise analyses to process images from these surveys.

The study asked these questions: Is CMECS useful for studies of the deep sea? How can CMECS be integrated into ongoing NOAA field efforts and databases for those field efforts? What changes or improvements could be made to facilitate adoption of the standard?

3.0 METHODS

To test the utility of CMECS for visual observation of the deep sea, this project applied CMECS to real-time observations and still image post-processing activities. The real-time observation tests engaged field teams from the *E/V Nautilus* and the *Okeanos Explorer* which were already surveying areas in the Northeast Pacific. Field trials were conducted on two expeditions over three months via telepresence on both vessels to log real-time, deep-sea observations using CMECS notation. Video images were classified from time on-bottom to time off-bottom. Images, navigation, and sensor data were joined using a time stamp. The images were organized as tables in MS Access and tagged in a series of passes to annotate geology, biology, and presence/abundance.

To test the use of CMECS for still imagery post-processing, lab trials were conducted on images from ROV dives in the Channel Islands National Marine Sanctuary from previous research cruises. The goal of both types of trials was to determine how field teams could comply with CMECS and what modifications might be necessary to accommodate the needs of the research and habitat suitability modeling communities.

3.1 Real-Time Observations

E/V Nautilus California Borderlands Expedition

The first field test was to observe live ROV dives from the *E/V Nautilus* California Borderlands expedition NA066 via telepresence from July 27 to August 9, 2016. Dives were conducted in Southern California between Malibu and San Diego. Locations are shown in Figure 3.

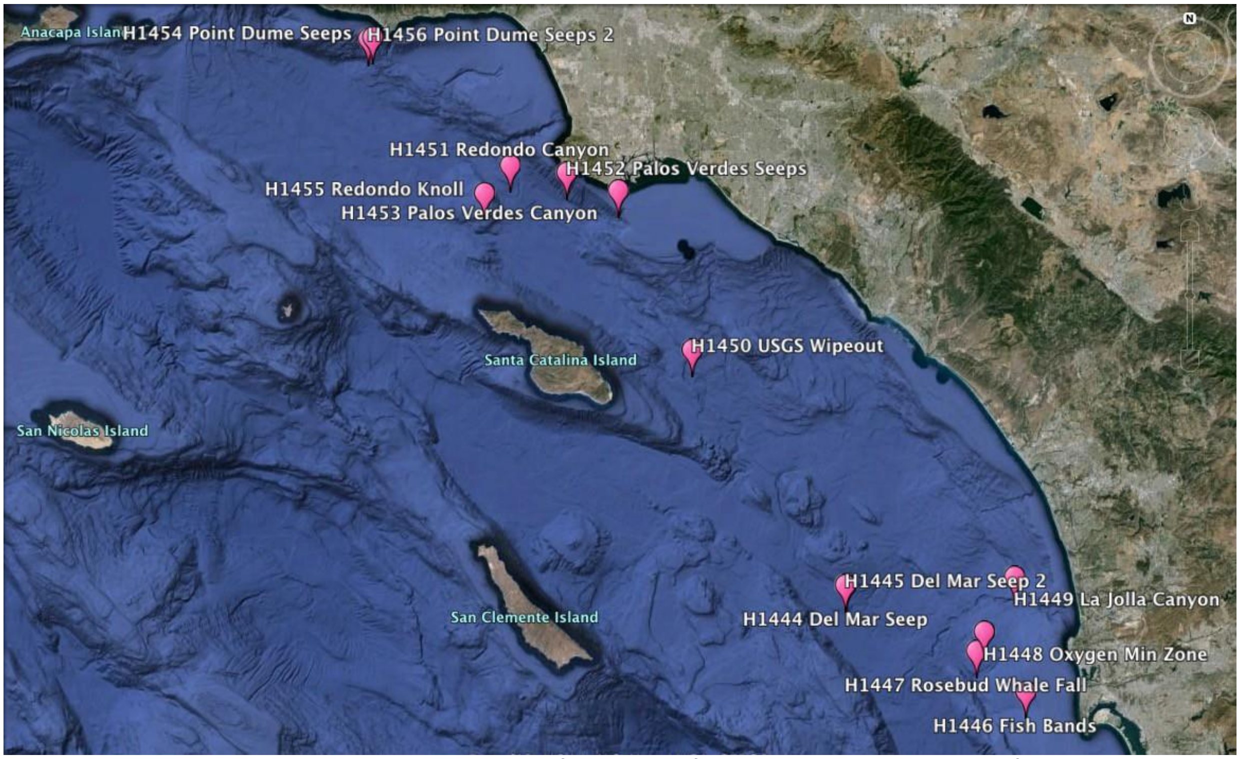

Figure 3 Map showing the dive locations from the California Borderlands Expedition of the *E/V Nautilus*. Details about these dives are provided in Table 2.

This expedition explored the canyons, seamounts, and seeps in the borderland region of the Southern California Bight (Table 2). The *E/V Nautilus* did not employ a standard observation log or code system at the time so CMECS notation was not used during *Nautilus* dive observations. However, general CMECS geological observations were recorded in the chat room via telepresence during the dives. This allowed for observation and participation in the role of a scientist ashore in a telepresence setting, and interaction with others in the chat room.

Data were gathered from sensors on the ROV, collated post-dive, and converted to CMECS units for the geoform and water column components (Table 1) in order to create a dive summary table (Table 2). These were captured in two columns titled "CMECS GC" and "CMECS WC." The remaining components were listed in the dive summary table legend. The CMECS water column layer for these dives, and all deep-sea benthic habitat observations, was the "marine oceanic layer," with "benthic" depth modifier. It is important to note that the water column data collected by the ROV during descent and ascent can also be qualified by CMECS modifiers if desired.

To determine which CMECS modifier to assign to a given parameter, the minimum and maximum values for that parameter are needed. For example, over the course of a dive, a temperature range from 11.5 to 14.0 °C would fall into the "cool water" modifier category, which encompasses the temperature range from 10 to <15 °C (see Table 1). Depth range is another parameter which fluctuates over the course of a dive. A depth range of 80 to 192 meters on a dive would fall into the CMECS Benthic Depth Zone "Circalittoral" which is defined as 30 to <200 meters (Table 1).

Table 1 CMECS parameters for converting numerical values to categorical units for the water column component. (FGDC, 2012)

Temperature Category	**Degrees (°C)**
Frozen/Superchilled Water	0 and below
Very Cold Water	0 to < 5 (liquid)
Cold Water	5 to < 10
Cool Water	10 to < 15
Moderate Water	15 to < 20
Warm Water	20 to < 25
Very Warm Water	25 to < 30
Hot Water	30 to < 35
Very Hot Water	≥ 35

Salinity Regime	**Salinity (practical salinity scale)**
Oligohaline Water	< 5
Mesohaline Water	5 to < 18
Lower Polyhaline Water	18 to < 25
Upper Polyhaline Water	25 to < 30
Euhaline Water	30 to < 40
Hyperhaline Water	≥ 40

Benthic Depth Zone Values	**Approximate Depth Range (meters)**
Littoral	Intertidal
Shallow Infralittoral	0 to < 5
Deep Infralittoral	5 to < 30
Circalittoral	30 to < 200
Mesobenthic	200 to < 1,000
Bathybenthic	1,000 to < 4,000
Abyssalbenthic	4,000 to < 6,000
Hadalbenthic	≥ 6,000

Oxygen Regime Values	**Oxygen Concentration (mg/L)**
Anoxic	0 to < 0.1
Severely Hypoxic	0.1 to <2
Hypoxic	2 to <4
Oxic	4 to <8
Highly Oxic	8 to <12
Very Oxic	≥ 12

Table 2 Dive summary table for *E/V Nautilus*; Date range: July 27-August 9, 2015.
Data Provider: Ocean Exploration Trust. CMECS Region: Northeast Pacific, Southern California.

CMECS Geoform: bight, borderland (=BB), submarine fan, submarine canyon, basin, whale fall, knoll, seamount, open upper slope
CMECS Water Column: marine oceanic. Depth: mesobenthic, bathybenthic. Temp: cold, very cold. Salinity: euhaline.
Oxygen: dysoxic, hypoxic, severely hypoxic. Biogeochemical: seep.

Date	Dive #	Locality	CMECS GC	CMECS WC	Dive Time	Start Lat.	Start Lon.	Depth (m)		Temp (°C)		Salinity (ppt)		Oxygen (mg/L)	
								Min	Max	Min	Max	Min	Max	Min	Max
27-Jul	H1444	**Del Mar Seep**	BB	Seep, Bathybenthic	16:57	32.9041	-117.781	993	1030	4.14	4.2	34.14	34.49	0.44	0.47
28-Jul	H1445	**Del Mar Seep**	BB	Seep, Bathybenthic	8:01	32.9039	-117.783	993	1026	5.53	6.77	34.3	34.38	0.67	-999
29-Jul	H1446	**350 Fish Bands**	BB, Open Upper Slope	Mesobenthic	3:32	32.698	-117.378	310	339	9.68	9.72	34.27	34.28	1.79	1.86
31-Jul	H1447	**Rosebud Whale Fall**	BB, Whale Fall	Mesobenthic	8:05	32.7765	-117.489	824	846	4.94	5.06	34.41	34.42	0.23	0.25
1-Aug	H1448	**OMZ**	BB	Seep, Mesobenthic	16:05	32.8127	-117.471	427	704	5.65	8.2	34.31	34.38	0.21	0.92
2-Aug	H1449	**La Jolla Canyon**	BB, Submarine Fan, Mouth of Canyon	Mesobenthic	10:49	32.9154	-117.401	449	647	6.13	8.03	34.3	3.34	-999	0.61
3-Aug	H1450	**USGS Wipeout**	BB	Mesobenthic	6:11	33.3492	-118.123	771	785	5.23	5.3	34.39	34.4	0.17	0.18
4-Aug	H1451	**Redondo Canyon**	BB, Basin	Mesobenthic	3:25	33.7989	-118.65	818	834	5.31	5.34	34.39	34.4	0.04	0.05
4-Aug	H1452	**Palos Verdes Seeps**	BB	Seep, Mesobenthic	8:43	33.6844	-118.404	583	800	5.45	6.45	34.32	34.39	0.08	0.35
6-Aug	H1453	**Palos Verdes Canyon**	BB, Submarine Canyon	Mesobenthic	12:03	33.6503	-118.287	41	449	7.95	13.02	33.24	34.32	0.79	9.55
6-Aug	H1454	**Point Dume Seeps**	BB	Seep, Mesobenthic	16:24	33.9415	-118.845	703	750	5.51	5.75	34.37	34.4	0.08	0.12
8-Aug	H1455	**Redondo Knoll**	BB, Knoll, Seamount,	Seep, Mesobenthic	16:00	33.6459	-118.590	534	713	5.53	6.77	34.3	34.38	0.09	0.47
9-Aug	H1456	**Point Dume Seeps**	BB	Seep, Mesobenthic	20:11	33.9385	-118.855	558	757	5.58	6.34	34.32	34.38	0.1	0.31

Table 3 Dive summary table for vessel *Okeanos Explorer*; Date range: August 8-September 3, 2015.
Data Provider: NOAA Office of Ocean Exploration and Research. CMECS Region: Mid-Pacific.

CMECS Geoform: ledge, lava field, deep coral carbonate mound, seamount, island shelf, island slope, metal reef.

CMECS Water Column: marine oceanic. Depth: mesobenthic, bathybenthic. Temp: cold, very cold. Salinity: euhaline. Oxygen: hypoxic, severely hypoxic, oxic. Biogeochemical: none

Date	Dive #	Locality	CMECS GC	CMECS WC	Dive Time	Start Lat.	Start Lon,	Depth (m)		Temp (°C)		Salinity		Oxygen (mg/L)	
								Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
28-Aug	1	**Cancelled**	--	--	--	--	--	--	--	--	--	--	--	--	--
29-Aug	2	**Keahole coral bed**	Ledge, Deep Coral Carbonate Mound	Mesobenthic	7:19	19.8042	-156.1265	313	394	7.92	10.09	34.14	34.22	2.25	5.77
30-Aug	3	**1868 Lava flow**	Lava Field, Island Slope	Mesobenthic	7:28	18.9593	-155.7316	444	455	6.73	7.85	34.23	34.25	1.55	2.24
31-Aug	4	**McCall Seamount**	Seamount	Bathybenthic	7:45	18.9837	-157.1129	2587	2715	1.57	1.72	34.67	34.67	3.45	3.78
1-Sep	5	**Swordfish Seamount**	Seamount	Bathybenthic	8:05	18.3124	-158.4563	953	2638	1.57	4.89	34.38	34.67	1.51	3.73
2-Sep	6	**Ellis Seamount**	Seamount	Bathybenthic	7:04	19.2335	-157.6123	2067	2153	1.96	2.21	34.63	34.64	2.75	3.07
3-Sep	7	**S19 Submarine**	Island Shelf, Metal Reef	Mesobenthic	3:33	null	null	null	403	--	--	--	--	--	--

Real-Time Observations (continued)

Okeanos Explorer EX1504L3 and EX1504L4

The second real-time field test occurred via telepresence during Legs 3 and 4 of the *Okeanos* Hohonu Moana expedition. Leg 3 took place on and around the main Hawaiian Islands and the Geologist Seamounts south of the main Hawaiian islands (Fig. 4). There were six ROV dives total, all at different sites (Table 3). The last dive took place at an undisclosed archaeological site, which provided a unique anthropogenic substrate. The substrate from the other dives was dominated by large volcanic boulder outcrops and large flat fields of volcanic gravel mixed with mud. Some of the dives contained smooth, flat, layered volcanic rock slabs, pillow basalts, or large square blocks of exposed volcanic rock. On Dive 02 there appeared to be an ancient coral reef (carbonate) that had become the substrate for other organisms. These unique marine substrates provided a valid first trial of real-time observations using CMECS terminology. These features are currently reflected in the lava geoform unit of the CMECS catalog.

A notation scheme was used to record CMECS substrate observations in the live chat room. This electronic record of observations from scientists around the world is retained as a record, or dive log, of the biological and geological observations during the dive. As with the *Nautilus* expedition, post-dive data was used to populate a dive summary table with the CMECS geoform and water column units (Table 3). This table is the recommended format for using CMECS as a "crosswalk."

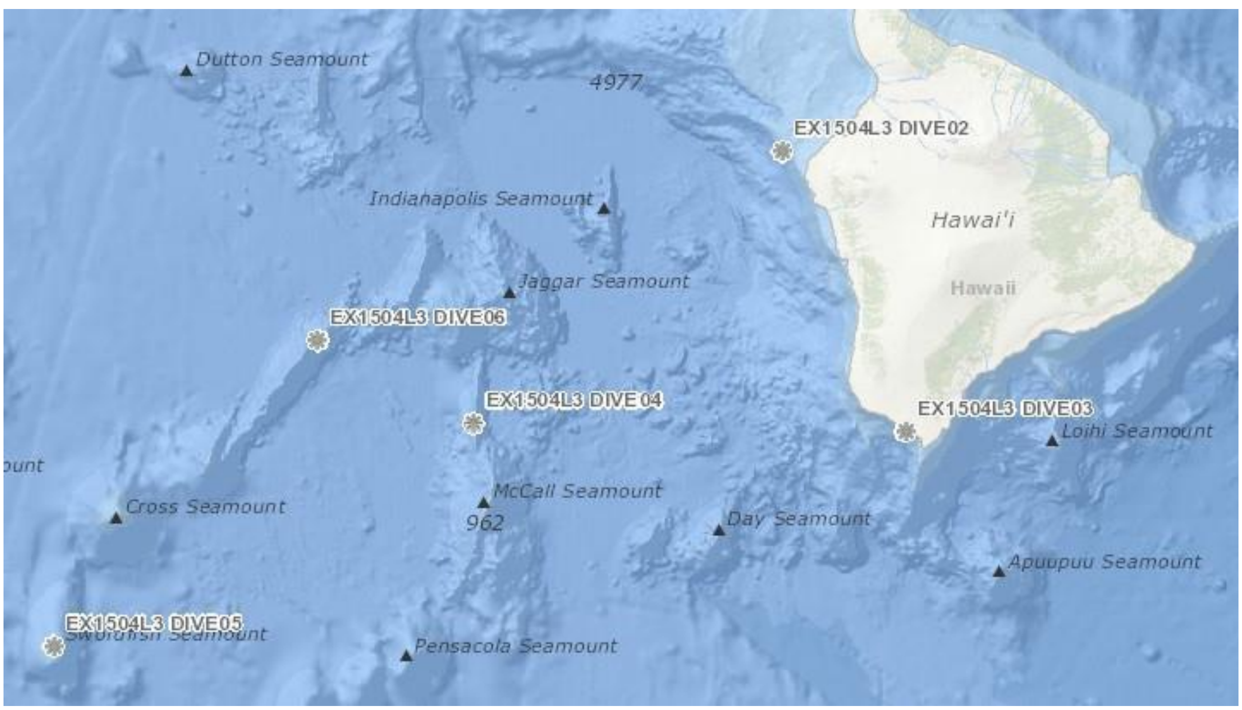

Figure 4 Map showing five of the dive locations from Leg 3 of the *Okeanos Explorer* cruise EX1504. Details about these dives are provided in Table 3

3.2 Office of Exploration Research Definitions and Shorthand Codes

Office of Exploration (OER) shorthand codes were used in conjunction with CMECS terminology and format to provide some continuity with other OER projects. Currently, the OER shorthand codes available for habitat and substrate include the following:

Geology
BUR – Burrow
COB – Cobble
MUD – Mud
ROC – Rock
RUB – Rubble
SAD – Sand
SED – Sediment
WAL – Wall

Lava Morphology
TAL – Talus
PIL – Pillow
ENT – Entrail
LOB – Lobate
SHE – Sheet
FOL – Folded
JUM – Jumbled
HAC – Hackly

Sediment Cover
LIG – Light
POC – Partial/Pockets
HEA – Heavy/Coalescent
BLA – Blanket

Feature
ASG – Axial Summit Graben
AVR – Axial Volcanic Ridge
CAR – Carbonate
CLI – Cliff
COL – Collapse
CON – Contact
FAU – Fault
FIS – Fissure
HAY – Haystack
HYX – Hydrothermal
PIL – Pillar
SCP – Scarp
SEP – Seep

3.3 Deep Sea Coral Research and Technology Program (DSCRTP) Definitions and Codes

The DSCRTP database schema consists of 108 different variables that can be used to describe any one observation of a deep-sea coral or sponge. The schema includes a field called "habitat," which is broadly defined) and another field to describe attachment point, called "substrate."

A comprehensive or "true" CMECS notation can include four components, numerous subcomponents, and several modifiers for one observation. As we have shown, the geoform and water column components can be captured in dive summary tables and dive logs. The substrate component is more dynamic. The geological character is likely to change over the course of a single dive. The nature of real-time ROV observations does not lend itself to lengthy descriptions as the landscape is constantly changing and it is ideal to have recorded observations and video images retain corresponding time stamps.

When entering CMECS data in a post-processing environment, more modifiers can be used, but in the interest of simplifying CMECS notations for the DSCRTP database, and for real-time annotation, a simple methodology was developed.

The following method for entering the habitat observations using CMECS-defined terminology and DSCRTP database format was employed. The distinction between Primary and Secondary should be made based on the spatial extent of the substrate types in the field of view as assessed through visual observation. For example, Primary substrate covered 50% or more of the image.

>CMECS Primary substrate/Secondary substrate; Rock type/Unconsolidated type E.g.,

>CMECS ROC/Unc; Lava/Gravel and MUD
This indicates lava rock is the primary substrate and unconsolidated gravel and mud are the secondary substrate.

E.g., >CMECS Unc/NA; SED
This indicates that unconsolidated sediment is the primary substrate and there is no secondary substrate (NA).

Entering ">CMECS" before the observation made it easier to sort and find these observations after the dive (Tables 4 and 5). In the above examples, ROC, SED, and MUD were OER shorthand codes meaning rock, sediment, and mud, respectively. There were several instances with no OER shorthand code so the observation was typed out in full. Observations were recorded when there was a change in substrate, or every 5-10 minutes if it stayed constant.

3.4 Use of CMECS with Coding Systems

Primary and Secondary substrate codes were provided along with their modifiers (Rock type and Unconsolidated type) in order to populate the "habitat" field in the national database.

Grain size classifications were taken from the CMECS (FGDC 2012) catalog, based upon those developed by Wentworth (1922) (Appendix A, Table A1). The Wentworth code was not applied directly because actual grain size measurements require sediment samples. Rather, a qualitative estimate was made based on visual observation. The ROV was fitted with lasers 10 centimeters apart that are visible in the live footage and the still images to assist in this process.

Primary Substrate: This is the substrate that covers >50% of the image frame.

- ROC - Rock = Igneous, metamorphic, or sedimentary rock with particle sizes greater than or equal to 4.0 meters (4,096 millimeters [mm]) in any dimension.
- Unc - Unconsolidated = Geologic substrate surface layer with particles 2 mm to <4,096 mm in diameter. Examples are sand, mud, and gravel.
- Unk - Unknown = Unable to be determined

Secondary Substrate: This is the substrate type covering <50% of the image frame.

- ROC - Rock = Igneous, metamorphic, or sedimentary rock with particle sizes greater than or equal to 4.0 meters (4,096 mm) in any dimension
- Unc - Unconsolidated = Geologic substrate surface layer with particles 2 mm to <4,096 mm in diameter. Examples are sand, mud, and gravel.
- Unk - Unknown = Unable to be determined
- NA = Used if the Primary Habitat covers >80% of the image frame.

Rock Type: If "Rock" was chosen in one of the substrate fields, type of rock is entered.

- Bed - Bedrock = Substrate with mostly continuous formations of bedrock/basalt.
- CAR - Carbonate = Often seen at the site of cold seeps as a result of bicarbonate being precipitated out of the water as calcium carbonate.
- Sandstone = A clastic rock composed of sand-sized detrital grains, a lithified sediment.
- WAL = steep or vertical areas on the seaward or exposed side of a reef. Although hard corals may be present, walls in this setting are formed by geologic processes and are not the result of reef-building activities by corals. A wall may be vertical or terraced, and is often referred to as the "drop-off."
- Lava - Lava Features = Structures and features created by volcanic activity. These can be found either along the coast or in deeper water. Terrain in lava features can be rough and broken or it can be relatively smooth; the terrain can also include vent structures (e.g., small cinder cones or spatter cones), surface flow structures (e.g., pressure ridges or tumuli), and small, intermittent areas covered with pyroclastics.
- Unk - Unknown = Unable to be determined.

Unconsolidated Type: Entered only if "Unc" was entered as one of the substrate choices.

- SAD - Sand = Surface layer contains no trace of Gravel and is composed of >90% Sand (particles 0.0625 mm to <2 mm in diameter).
- SED - Sediment = Used for gravel/sand/mud/clay mixture that cannot be determined more specifically.
- COB - Cobble = Contains >80% Gravel, with a median Gravel size of 64 mm to <256 mm.
- MUD - Mud = Surface layer contains no trace of Gravel and is composed of 90% or more Mud (particles less than 0.0625 mm in diameter); the remainder (<10%) is composed of Sand (particles 0.0625 mm to <2 mm in diameter).
- RUB - Rubble = Intended for use in biogenic and anthropogenic material and defined by substrate that is dominated by median particle sizes of 64 mm to <4,096 mm in any dimension, equivalent to Cobbles and Boulders.
- RUB COR - Coral Rubble = A majority of the substrate is loose accumulation of dead coral.
- Shell Hash = Loose shell accumulations with a median particle size of 2 mm to <64 mm (Granules and Pebbles). Shells may be broken or whole.

Table 4 Event log excerpt from telepresence observations for EX1504L3 Dive 04
Frame grabs for each observation in Appendix B, Figures B1 and B2.

08/31/201	20:25:07	okexnav	LAT :18.98289	LON : -157.	DEPTH :2698.	TEMP : 1.63898C
08/31/201	20:27:12	rachelbassett	CMECS Rock/Unc; Lava/SED			
08/31/201	20:29:44	rachelbassett	Vesicular lava.			
08/31/201	20:30:20	rachelbassett	Manganese coating			
08/31/201	20:35:15	okexnav	LAT :18.98292	LON : -157.	DEPTH :2699.	TEMP : 1.63693C
08/31/201	20:39:19	brucemundy	SPO			
08/31/201	20:40:32	brucemundy	SPO			
08/31/201	20:41:25	rachelbassett	CMECS Unc/Unc	SED/RUB lava		
08/31/201	20:42:17	J.R.	TAL CON with SED and RUB			

Table 5 Event log excerpt from telepresence observations for EX1504L3 Dive 05
Frame grabs for each observation in Appendix B, Figures B3 and B4.

09/01/2015	22:16:54	rachelbassett	CMECS Rock/Unc	Lava boulders and large outcrop/LIG SED blanket between ROC
09/01/2015	22:17:51	rachelbassett	Can we get lasers?	
09/01/2015	22:18:17	tinamolodtsova	CRA on CORC	
09/01/2015	22:19:46	tinamolodtsova	SQA	
09/01/2015	22:21:39	tinamolodtsova	Scleractinia	
09/01/2015	22:21:55	okeanosexplorer	COR scleratinia	
09/01/2015	22:22:08	tinamolodtsova	Madrepora?	
09/01/2015	22:26:55	tinamolodtsova	take fallen branchlets	
09/01/2015	22:30:32	tinamolodtsova	Chris	zoom at fallen dead branchlet ahead. what is growing at?
09/01/2015	22:32:49	tinamolodtsova	SHI	
09/01/2015	22:37:15	tinamolodtsova	CRI on COR	
09/01/2015	22:37:17	rachelbassett	lave WAL.	
09/01/2015	22:37:20	rachelbassett	Wow!	
09/01/2015	22:38:12	rachelbassett	CMECS ROC/NA	Lava WAL and slump.
09/01/2015	22:40:17	rachelbassett	White substance on lava boulder. CAR?	

For the last dive (Dive 12) of Leg 4 of the Hohonu Moana expedition it was decided that logging could be simplified further for ease of entry. CMECS has an induration modifier based on the Greene et al. (2007) classification scheme (Appendix A) that has been used by other investigators and fits with the CMECS substrate units utilized in the DSCRTP database. The classifications are "h" = hard bottom - strongly consolidated fine sediment with low water content, or rock outcrop, or bedrock; "m" = mixed hard and soft bottom - a blend of hard and soft substrate materials (e.g., local sediment cover of bedrock); and "s" = soft bottom - loose, fine, unconsolidated, or sediment-covered substrate with a high water content (Greene et al. 2007; FGDC 2012).

This scheme was modified for ease of entry, using H and S to replace the "ROC" and "Unc" for the primary and secondary entry codes that were used in Leg 3 and the beginning of Leg 4. This decision was based on the overall goal of the project which is an understanding of the suitability of the substrate to support deep corals, and is based more on induration than the substrate composition. This did not change the information being entered, it simply provided a shorter entry code. Also, "CMECS" was dropped at the beginning of each entry (Table 6).

Thus, the new codes for recording primary and secondary substrate became:

HH = Hard/Hard
HS = Hard/Soft }
SH = Soft/Hard } Mixed
SS = Soft/Soft
Unk = Unknown

The new format became:

E.g., >HH; Lava boulders (no secondary substrate)
E.g., >SH; SED/Outcrop (soft and hard primary and secondary substrates)

Table 6 Event log excerpt from telepresence observations for EX1504L4 Dive 12
Frame grabs for each observation in Appendix B, Figure B5.

09/25/201	20:45:26	Kimberly	the rubble looks to be significantly smaller sized fragments
09/25/201	20:45:34	tinamolodtsova	Echiuridae?
09/25/201	20:45:45	rachelbassett	HH Lava RUB with medium COB
09/25/201	20:45:46	tinamolodtsova	no
09/25/201	20:45:48	tinamolodtsova	HYD

3.5 Still Image Post-Processing

Real-time seafloor observation and annotation is less common than annotations recorded ashore following a research cruise, using video or still images of ROV footage collected in the field. Therefore, the CMECS terminology was also tested with still images, recording similar substrate and habitat information captured during the live observations.

R/V Shearwater **Channel Islands – Santa Rosa Island 2015**

An expedition aboard the *R/V Shearwater* in the Channel Islands National Marine Sanctuary in 2015 provided hundreds of still images from ROV exploration. A Microsoft Access database was created for entry of observations for these images. To conform to the DSCRTP database schema and to be consistent with the real-time observation notation, the Access database included fields for primary habitat, secondary habitat, and descriptors for the types of those substrates (habitats). All four of these fields populate the "habitat" field in the DSCRTP database. There was no need to be concise as with real-time observations, therefore rock and unconsolidated were written in full and retained as the habitat categories rather than using H (hard) and S (soft) as in the live notation.

An additional field, "attachment point", was added to the Access database to populate the "substrate" field in the DSCRTP database. Attachment point was used to refer to the substrate to which an observed coral or sponge was attached. Drop-down menus rather than OER shorthand codes were used for entry into the Access database (shown in Appendix C).

The seafloor geology around Santa Rosa Island is dominated by Miocene sedimentary and volcaniclastic rocks (Dibblee and Ehrenspeck 2002). To accommodate this, sandstone was included as a menu choice for rock type. Cobble as a rock type and gravel as an unconsolidated type were also added, as many areas of these substrates had been noted during previous observations. These choices are all within the existing CMECS substrate components. We created subforms for biology, geology, and debris. This allowed for more rapid specialized observation in each of these categories.

The categories available for entry in the Access database follow: Refer to Appendix C for examples of the Access database entry page.

Primary Habitat: The substrate which covers >50% of the image frame.

- Rock = Igneous, metamorphic, or sedimentary rock with particle sizes greater than or equal to 4.0 meters (4,096 mm) in any dimension.
- Unconsolidated = Geologic substrate surface layer with particles 2 mm to <4,096 mm in diameter. Examples are sand, mud, and gravel.
- Unknown = Unable to be determined

Secondary Habitat: The substrate which covers <50% of the image frame.

- Rock = Igneous, metamorphic, or sedimentary rock with particle sizes greater than or equal to 4.0 meters (4,096 mm) in any dimension
- Unconsolidated = Geologic substrate surface layer with particles 2 mm to <4,096 mm in diameter. Examples are sand, mud, and gravel.
- Unknown = Unable to be determined
- NA = Used if the Primary Habitat covers >80% of the image frame.

Rock Type: If "Rock" was chosen in one of the substrate fields, type of rock was entered.

- Bedrock = Substrate with mostly continuous formations of bedrock/basalt.
- Carbonate = Often seen at the site of cold seeps as a result of bicarbonate being precipitated out of the water as calcium carbonate.
- Cobble = Contains >80% gravel, with a median gravel size of 64 mm to <256 mm.
- Sandstone = A clastic rock composed of sand-sized detrital grains, a lithified sediment.
- Unknown = Unable to be determined.

Unconsolidated Type: Entered only if "Unconsolidated" was one of the substrate choices.

- Coral Rubble = A majority of the substrate is loose accumulation of dead coral.
- Shell Hash = Loose shell accumulations with a median particle size of 2 mm to <64 mm (Granules and Pebbles). Shells may be broken or whole.
- Gravel = All rock fragments 2 mm to <4,096 mm.
- Sediment = Silt/sand/mud/clay that cannot be determined more specifically.

Attachment Point: The correct substrate to which the identified coral or sponge is attached.

- Rock = Igneous, metamorphic, or sedimentary rock with particle sizes greater than or equal to 4.0 meters (4,096 mm) in any dimension
- Unconsolidated = Geologic substrate surface layer with particles 2 mm to <4,096 mm in diameter. Examples are sand, mud, and gravel.
- Anthropogenic = Examples would be marine debris, fishing gear or shipwreck.
- Other = Substrate cannot be determined or is not one of the previous three categories.
- NA = No coral or sponge visible in the image.

4.0 RESULTS

Thirty-two ROV dives from two telepresence expeditions and one field survey and more than 6,400 still images were analyzed using a simple CMECS annotation.

4.1 The Utility of CMECS for Visual Observations

Although the main concentration for this study was on the CMECS substrate component, the water column and geoform components add vital information that can be utilized for other scientific purposes and should not be overlooked. To enhance the geological characterization of seafloor habitat, geoform and water column components can be captured in a single description for a whole dive. Several descriptors can be concatenated, such as that shown in the captions of the dive summary tables - Tables 1 and 3. The geoform component was accomplished using geopositional data in a digital map atlas, or GIS. The water column component was accomplished using data gathered from the CTD sensor. CMECS contains units in both of these components that allow for large-scale or detailed regional and local descriptions, which enables investigators to share more specific details of their dive observations.

The CMECS substrate component is most useful at fine spatial resolution < 10 m^2. Substrate characteristics vary over smaller spatial scales within a survey and require special attention in annotation. For real-time substrate observations, the original CMECS notation format was deemed too complex to enter while keeping up with the constant movement of the ROV. To remedy this, a more concise format was used for the last dive of the *Okeanos* expedition. This new format, using a combination of the induration codes H (hard) and S (soft), made observing and logging in real-time much more effective by increasing the likelihood that image timestamps and observations were periodic and synchronized. This new format did not change the CMECS units of rock and unconsolidated, but provided a shorter notation for that same information.

During live observations, the NOAA OER shorthand codes, SED, MUD, ROC, and RUB were used fairly often. However, volcanic rock was the main substrate for most of the dives in this study. Although there are several lava morphology codes available in the OER code list, those could only be used by someone who is very familiar with lava morphology. Missing shorthand codes made it necessary to type out complete words for this and many other observations.

For the still images, substrate choices were included for each field which served to refine the descriptions without changing the standardized fields. Depending on the local geological morphology, appropriate substrate types from the CMECS catalog were added to drop down menus in the Microsoft Access data entry database. Based on the field tests in this study, a useful observation notation for live footage and still images using CMECS units was finalized.

4.1.1 The Utility of CMECS for Real-Time ROV Observations

Format Notation:
Primary Habitat/Secondary Habitat; Rock type/Unconsolidated type.

Rock type and unconsolidated type were entered to correspond with the primary and secondary habitat. In other words, if primary habitat was soft and secondary habitat was hard the unconsolidated type was entered first and the rock type second.

This entire notation was submitted as one observation into the DSCRTP database field for "habitat." Attachment point was not included in live observations. The codes used in this notation for Primary and Secondary Habitat were:

HH = Hard/Hard
HS = Hard/Soft } Mixed
SH = Soft/Hard } Mixed
SS = Soft/Soft
Unk = Unknown

The H and S were used synonymously for the CMECS substrate units of rock and unconsolidated, but were quicker to type in during dynamic observations.

The Rock type and Unconsolidated type both have numerous CMECS units from which to choose allowing the observer flexibility within the notation. OER shorthand codes were used when available for ease of entry. For this study, volcanic rock (lava) was the rock type and unconsolidated type most observed. It had neither a CMECS unit nor an OER shorthand code. Examples of this live observation notation are as follows:

HH; Bed
(Hard primary habitat/no secondary habitat; Bedrock as the rock type)

HH; Lava outcrop and COB
(Hard primary/hard secondary; Lava outcrop as primary rock type/cobble as secondary rock type)

SH; SED/CAR
(Soft primary/hard secondary; Sediment as the unconsolidated type/carbonate as the rock type)

SS; Shell hash and SED
(Soft primary/soft secondary; Shell hash as primary unconsolidated type/sediment as the secondary unconsolidated type)

4.1.2 The Utility of CMECS for Post-Dive Still Image Observations

Because each image could be observed with no time constraint, a drop down menu for each observation type was provided in an Access database (shown in Appendix C). They are the same observation types as those for live observations, with the addition of attachment point for corals and sponges. The first four observation fields were still grouped as one observation and populated the "habitat" field when submitted to the DSCRTP database (Hourigan et. al 2015).

Attachment point was entered into the DSCRTP database in the "substrate" field.

Primary Habitat Secondary Habitat Rock type Unconsolidated type	} DSCRTP "Habitat"
Attachment Point	DSCRTP "Substrate"

4.2 The Utility of CMECS for Geomorphological Characterization for Biological Purposes

CMECS is useful in characterizing the surficial geology of seafloor habitat, as well as the larger geo-morphological features that are the subject of exploration. CMECS geoform and water column components include seamounts, canyons, whale fall, and seep environments, among others. Geomorphological features like these are often indicated in both pre- and post-dive exploration documents used during field surveys, and they are accessible from these reports.

Dives are one of the repeated measures of a deep-sea expedition. Seamount dives, canyon dives, or seep dives are a common vernacular for ROVs, AUVs, and submersibles. Dives are annotated as an independent repeated measure aboard an expedition, each with their own number, plan, waypoints, and report. Wood's Hole Oceanographic Institution maintains records for DSV Alvin and Jason ROV that go back decades, for thousands of dives. Appendix E contains representative dive plans from the

Okeanos Explorer and the *E/V Nautilus*. Each dive plan has a heading stating the location, date and other information about the dive.

A new field or line could be added to standard dive plans and reports to indicate CMECS geoforms, water column, and substrate components. For example, the *Okeanos Explorer*'s post-dive summary has a 'General Area Descriptor' section that may be used. Likewise, the *E/V Nautilus* Dive Reports could accomodate the CMECS geoforms in the header. The *E/V Nautilus* also has a post-cruise metadata spreadsheet, or Dive Log, that could include a column for the CMECS geoform. Appendix F includes post-dive summaries from the *Okeanos Explorer* and the *E/V Nautilus*. Pro-active education of the crew may facilitate adoption of CMECS standards, and provide an opportunity to compile, search, and filter this information in the future. CMECS field guides and field apps should be prepared and distributed to field teams to foster further development.

5.0 DISCUSSION

There are a number of classification systems currently in use with potential for deep-sea applications (CATAMI, EUNIS, etc.). CMECS was designed to describe features of the marine environment independently from any particular observation technology or geography. It was also intended to be scale-independent and thus applicable at site specific to regional and global scales, acknowledging that levels of detail and resolution would vary across these ranges. This approach was necessary to achieve the data integration goals behind the development of the standard.

The need for standardization is growing with the increasing need to characterize, classify, and predict habitat that is suitable for deep-sea coral and sponge communities, with the eventual goal of protecting these fragile ecosystems. Many research vessels, even telepresence-enabled vessels, remain an untapped resource for useful seafloor characterization data. This is due partly to the lack of standardized observation terminology and methodology.

5.1 CMECS Components are Useful for Dive and Cruise Annotation

This study has demonstrated that CMECS provides a relevant standard terminology for substrates, geoforms, water column data, and biological observations in the deep sea. Deep-sea observations can fit into the schema whether these observations are made in real-time or post-cruise. The CMECS approach is also compatible with NOAA's National Database of Deep-Sea Corals schema, which enables the public to use these data in a unified, accessible platform.

The OER shorthand code system and standard observation logging method, could also easily incorporate CMECS notation. The adoption of CMECS terminology is encouraged for research vessels that conduct benthic surveys but do not use a standard classification system. This would simply be a matter of educating the scientific observers and encouraging the use of a standard observation methodology.

Habitat suitability modeling is a valuable and necessary tool in the effort to utilize available data and expand understanding of the distribution of deep-sea coral and sponge communities. Predictive maps help to fill data gaps (areas that have not been surveyed) and show where deep-sea coral and sponge communities may potentially be found. A standard, real-time logging method for video observations helps to alleviate post-cruise data backlog, and enables researchers to generate usable products for immediate use in further research (Anderson et al. 2007). In the case of habitat suitability modeling this is preferred, because it increases the availability of current, relevant data by which to calibrate and improve these models.

5.2 Operational Procedures for CMECS Compliance

The incorporation of CMECS units into cruise reports and *in-situ* observations does not appear to be a costly or time-consuming venture, so long as the choice of spatial scale, and the level of application, is appropriate to the research at hand. Cruise reports, dive plans, and dive summaries, can be modified to include geoform, water column, substrate, and other CMECS information. Templates should be developed by NOAA agencies and provided to field workers to enable principal investigators to easily assess deep-sea habitat and share their results. Appendices E and F show some examples.

For cruise reports to be consistent with CMECS, post-dive summary tables using CMECS units are recommended. As demonstrated in Tables 1 and 3, the geoform and water column CMECS units are easily incorporated. The geoform component describes the overall setting for the observations, whether local or regional. Examples are: seamount, canyon, and continental shelf. The water column component enables investigators to extract information at finer scales that are most useful in habitat suitability models and other data products. Summary tables can display relevant CMECS information for each dive to show the range of habitats explored by an expedition. In many cases, integer values are more informative than the CMECS units, which are categorical. Mean, maximum, and minimum values of depth, temperature, and oxygen are particularly useful for "crosswalking" sensor output to CMECS water column categories.

It is not uncommon for researchers to require information outside the CMECS conceptual domain. In those cases, adding CMECS units may not benefit the study at hand but may add broader impact to the results by facilitating data integration by subsequent researchers with different questions.

The CMECS Implementation Group has been developing CMECS metadata standards as a way to easily access CMECS compliant data from a variety of federal and state clearinghouses and portals. This will include development of a CMECS metadata thesaurus and keywords. It will also include recommendations on how to create an informative title for a dataset. Some users may crosswalk their own data schema to apply the CMECS terminology, so the CMECS code-set may be expressed in data attribution as a way to ensure data discoverability.

5.3 Suggestions for Better Integration of CMECS into Telepresence-Enabled Expeditions

It was observed during both telepresence expeditions that the majority of logged observations in scientific chat rooms were based on the biology that was present in the habitat. Very few geological observations were recorded unless a specific inquiry was made during the dive. The correlation between the geology type and biology type of corals and sponges is fairly well-established, so this makes it necessary to put more emphasis on creating a balance between both types of observations. Better annotation of surficial geology is needed to enhance descriptions of the seafloor and to aid interpretation of maps from acoustic sensors.

Based on the substrates encountered during the real-time and post-dive still observation tests in this study, the following suggestions for the addition of terminology, to shorthand codes and the CMECS units, would make substrate habitat observations quicker and more efficient. The suggestions also serve to integrate the two systems into a single methodology.

Shorthand Codes

- Add REF for reef and FOS for fossil.
    - What was possibly an ancient reef was encountered as main substrate on one of the Leg 3 dives of the Hohonu Moana expedition (Appendix D, Fig. D1). CMECS has a substrate class for Coral Reef Substrate that pertains to either living or non- living coral substrate.
- Add OCRP for outcrop and/or BLDR for boulder.
    - More than one observed area had very large exposed boulders that could best be described as outcrops (Appendix D, Figs. D2 and D3). CMECS has a geoform subcomponent for Rock Outcrop and a substrate subcomponent for Boulder.
- Add LAV as a generic lava (volcanic rock) code.
    - As mentioned previously, the very specific lava morphology codes currently available are useful for those who are knowledgeable in lava morphology. However, for general use, a broader code is necessary.

CMECS Units

- Add Lava or Volcanic as a rock type.
- Add Lava or Volcanic as a substrate type.
    - Currently, Lava Field/Plain and Lava Levee are CMECS geoform components, and the only CMECS units that include volcanic rock. Lava/Volcanic as a rock type or as an unconsolidated type is not available for use. On this expedition, both of these were appropriate as descriptors for substrate and should be considered in the CMECS substrate descriptors. (Appendix D, Figs. D4-D6)
- Add Talus as a geoform or substrate .
    - The U.S. Geological Survey website defines Talus as: "An outward sloping and accumulated heap or mass of rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a cliff or very steep, rocky slope, and formed chiefly by gravitational falling, rolling, or sliding." (USGS 2015). This type of substrate can be used in marine and terrestrial settings and, again, was appropriate in some of the dives.

For the purposes of this study, the focus was on the habitat and substrate fields in the DSCRTP national database for use in habitat suitability mapping. Within those fields, we included primary and secondary habitat, a brief description of those habitats, and the coral and sponge attachment point (substrate) using CMECS units. The recommended addition of a DSCRTP field for vertical relief would serve to enhance the accuracy of habitat suitability predictions as predictions include a variety of spatial scales. Habitat suitability is just one application. Overall, the national database would benefit from a standard habitat nomenclature that could be used for any search.

5.4 The Utility of CMECS for Local and Regional Observations

While CMECS is useful for visual observation annotation and benthic characterization for biological purposes, in order to increase the amount of predictive data for habitat suitability, both induration and vertical relief should be recorded. Substrate relief is not currently captured in the DSCRTP database, but is of vital importance when predicting the presence of corals and sponges (Bryan and Metaxas 2007, Stone et al. 2014, Tissot et al. 2006, Dartnell et al. 2014). A column for vertical substrate relief could be added to the DSCRTP national database for this purpose. Useful definitions for vertical relief were established by Anderson et al. (2007) and are used by CATAMI in Australia (CATAMI 2013).

The Anderson measures provide a finer scale than the CMECS elevation profile values for local and regional observations as can be observed in Table 7. Tables 7 and 8 are "crosswalks", or comparisons of similar values from different systems.

Table 7 Crosswalk of Anderson et al. 2007 Vertical Relief with CMECS Elevation Profiles.

Anderson et al. Vertical Relief Values	CMECS Elevation Profile Values
Flat (0 m)	None (0m)
Low relief (<1 m)	Low (0.1 - <2 m)
Moderate relief (1-3 m)	Medium (2- <5 m)
High relief (>3 m)	High (≥ 5 m)
Rock walls (high-relief with >80° incline)	No equivalent

Based on this study, the CMECS oxygen regime values were not very helpful for much of the Pacific, especially the California deep margin basin. The oxygen levels in the Pacific are much lower than those in the Atlantic, and Pacific taxa have different oxygen thresholds than Atlantic taxa (L. Levin, personal communication, November 2015). The oxygen regime values must, therefore, be at a finer scale for this region than the CMECS values. The suggested values for the Pacific region have been crosswalked with the current CMECS values in Table 8. Augmentation of the existing CMECS categories for oxygen regime values is recommended.

Table 8 Crosswalk of CMECS Oxygen Regime Values with Pacific Oxygen Regime Values.

CMECS Oxygen Regime Values (mg/L)		Suggested Oxygen Regime Values for the Pacific (µm)	
Anoxic	0 to < 0.1	Anoxic	0 (absence)
No Equivalent	--	Dysoxic	0.1 to 5 (~0.003 to 0.16 mg/L)
Severely Hypoxic	0.1 to <2	Severely Hypoxic	5 to 22 (~0.16 to 0.69 mg/L)
Hypoxic	2 to <4	Hypoxic	22-63 (~0.69 to 2 mg/L)
Oxic	4 to <8	Oxic	>63 (>2 mg/L)
Highly Oxic	8 to <12	No equivalent	--
Very Oxic	≥ 12	No equivalent	--

During this study it was discovered that some parameters are unique at local or regional scales. Examples are the volcanic substrate in the mid-Pacific and the oxygen regime values in the Pacific. It is the goal of the CMECS working group that CMECS be flexible enough to be used on any scale without losing utility (FGDC 2012). However, CMECS is also a dynamic standard and may be refined through a peer-reviewed process in light of new information (FGDC 2012). When local conditions differ considerably from the CMECS catalog units, it is suggested that the user continue to capture relevant local parameters and features and propose them as provisional units to future updates of the CMECS standard.

6.0 RECOMMENDATIONS

The suggestions found herein are based on a handful of expeditions. It will be necessary to use the CMECS terminology on more expeditions in order to encounter diverse types of substrate and further refine and edit the OER and other shorthand codes, the CMECS units, and DSCRTP database entry options. Collaboration between data managers at NOAA and research vessel scientists such as those on the *Okeanos* and *Nautilus*, can provide a combined effort toward standardization. Eventually, dive codes for all the CMECS units should be created for a truly integrated methodology.

The following section summarizes the key recommendations from this study as well as some broader suggestions for operationalizing CMECS and improving the standard.

- The upper level geoform scale is highly relevant to the deep-sea exploration enterprise. Geoforms are part of the exploration vernacular (e.g., seamount, canyon), and may be used to characterize dives, but not necessarily cruises.
- The geoform component may be integrated into dive logs and dive summaries at NOAA Office of Ocean Exploration and Research (OER), Ocean Exploration Trust (OET), and other federally-funded deep-sea benthic survey teams.
- The water column component may be reported as a standard table showing maximum and minimum values for depth, oxygen, temperature and salinity for each dive. Computer code should be developed to "crosswalk" this table into various CMECS categories.
- The present categorical definitions for water column need to be reviewed, and possibly augmented based on feedback/comments received from surveys of other observers, in order to be more comprehensive and regionally representative.
- Substrate values should be incorporated into live annotation protocols aboard telepresence cruises. Periodic data entry is recommended, preferably by a trained geologist. Primary geology, secondary geology, and relief should be recorded.
- The recommended periodic interval for data entry ranges from every 5 or 10 seconds to every 5 minutes, depending on regional standards, mission objectives, and staff available.
- Some substrate categories need new modifiers. Add "volcanic" or "volcanic rock" as a modifier to substrate descriptions in the CMECS catalog. It would also be helpful to add subcomponents such as "pillow basalt".

In summary, this study found that CMECS is useful and applicable for deep-sea exploration. The Federal Geographic Data Committee standard can be incorporated into deep-sea research efforts with minimal cost and impact. Some modifications may be required to make the CMECS standard useful to deep-sea surveys, and some new annotations may be required to make deep-sea surveys compliant with CMECS. However, aspects of the CMECS standard can feasibly be met with relatively minor modifications to standard operating procedures.

The team of the NOAA ship *Okeanos Explorer* will pilot test a new annotation software application, SeaScribe, in 2017. The software will be customized for video annotation in a real-time setting via telepresence by participating scientists around the world. The NOAA Office of Exploration and Research (OER) is working to incorporate CMECS into the annotation schema to the maximum extent practicable. OER shorthand annotation codes may become obsolete as this new annotation software is developed. However, a controlled vocabulary is still recommended to standardize data entry and make it more efficient.

CMECS could be employed as an organizational schema for sorting and filtering a geo-database of deep-sea submersible dives. The US deep-sea exploration community should seek to develop a new spatial database that uses CMECS categories to tag deep-sea dives from a large number of institutions. A geodatabase of CMECS attributed dives would allow for useful and interesting data queries (e.g. show all dives from Pacific seamounts, show dives in anoxic depths, or dives from Atlantic canyons) to catalyze and promote deep-sea science and discovery.

As the marine science community continues to move toward an ecosystem-based management approach, incorporating all possible features of a community becomes a necessary part of a synergistic ecological overview. Ensuring that there is a common terminology and consistent observation methods for these features will make understanding the relationships within an ecosystem more accurate and useful, which will enhance our ability to predict the presence or absence of deep-sea ecosystems and, ultimately, to conserve them.

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9.0 APPENDICES

Appendix A - Background – A Timeline and Review of Geological Characterization in the Northeast Pacific

1922 – Scale of terms for clastic sediments

Although not exclusive to the Northeast Pacific or the marine environment, the Wentworth scale has been the standard used by geologists since its publication (1922). The scheme was used as the basis for the CMECS substrate grain size component because marine sediments are not considered "soils," rendering the existing soil-based standards inappropriate.

Table A1 Wentworth grain size classification

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	Gravel
	64		-6.0	Pebble	Gravel
	4		-2.0	Granule	Gravel
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	Sand
1/2	0.50	500	1.0	Medium sand	Sand
1/4	0.25	250	2.0	Fine sand	Sand
1/8	0.125	125	3.0	Very fine sand	Sand
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	Silt
1/64	0.0156	15.6	6.0	Fine silt	Silt
1/128	0.0078	7.8	7.0	Very fine silt	Silt
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

This scale is the foundation for the following characterization classifications as well.
A number of schemes have been in use since 1999 using a combination of substrate descriptions, schemas, and classifications. All of them address induration, some allow for a separation of primary and secondary substrate, and most of them include vertical relief.

1999 – A classification scheme for deep seafloor habitat

One of the earliest classification schemes to describe deep marine benthic habitats was created using geophysical data and in situ biological and geologic observations as a standard method to describe and compare habitats among scientific disciplines and geographic regions (Greene et al. 1999). Originally created for use along the west coast of North America, the hierarchical classification scheme begins with the broad category of habitat:

Megahabitats: 1 km - tens of km and larger. E.g., canyons, seamounts, lava fields.
Mesohabitats: tens of m to 1 km. E.g., small seamounts, canyons, cobble fields. Macrohabitats: 1-10 m. Seafloor materials and features. E.g., boulders, reefs, and sink holes. Microhabitats: < 1 m. E.g., sand, pebbles, crevices.

While very descriptive, this scheme lends itself to lengthy descriptions such as the one below.

> E.g., "Flat megahabitat on continental shelf in intermediate water depths (0-100 m). Mesohabitats include sand waves, sand stringers and cobble patches interspersed with rock outcrops; isolated boulders and pinnacles are examples of macrohabitats."

2007 – A coded classification scheme and its application

Nearly eight years later, Greene et al. (2007) further refined this methodology in light of new mapping technology and the advent of GIS as a powerful mapping tool. The resulting attribute codes, originally intended for use in California and Alaska, have been expanded to the Pacific, the Arctic, and the Antarctic regions (Greene et al. 2007). One shortcoming of the earlier methodology was that it had only brief modifiers for vertical relief, which is a critical component of deep-sea coral habitat (Bryan and Metaxas 2007, Guinotte and Davies 2014, Dartnell et al. 2014). The new codes include a parameter for rugosity which is not the same as relief, but does address roughness of the seafloor.

The attribute code contains four primary characters and three optional primary characters.

Primary Characters:

1. Megahabitat
2. Bottom Induration (soft/mixed/hard)
3. Meso-/Macrohabitat
4. Mega-/Macrohabitat Modifier

Optional Primary Characters:

1. Small-scale Slope (in degrees)
   1) flat (0-5°), 2) sloping (5-30°), 3) steeply sloping (30-60°),
   4) vertical (60- 90°), and 5) overhang (>90°)
2. Small-scale Rugosity (calculated from bathymetric data)
   A) very low rugosity (-1.0), B) low rugosity (0-1), C) moderate rugosity (1-2),
   D) high rugosity (2-3), and E) very high rugosity (3+)
3. Geologic Unit (Geologic age)

E.g., "Ssc_u1B(Qm)" = Shelf, soft sediment, canyon, unconsolidated, flat slope, low rugosity(Quaternary age of marine origin)

The key utility of the approach is the application of primary and secondary codes to describe "mixed" habitats. This is important because mixed habitats are routinely encountered. To utilize this feature, bottom induration is further extended to specify primary and secondary substrate when there is a mixed substrate type. Adding gravel and sand as the primary and secondary substrate type to the previous example would look like this, "Ss(g/s)c_u1B(Qm)". Figure A1 uses this attribute code to describe an area of Southeast Alaska.

The strength of this habitat characterization approach by Greene et al (1999, 2007) is the fine degree of geological detail, including (in Figure A1) 14 different geological characterizations. The drawback of the approach is that codes are long and complex, they require some degree of expert knowledge, and the number of substrates to be verified is large. Furthermore, the response of corals and sponges to some types of hard or soft bottom might not be different than other types of hard or soft bottom, so the approach may "over predict" habitat in some regard.

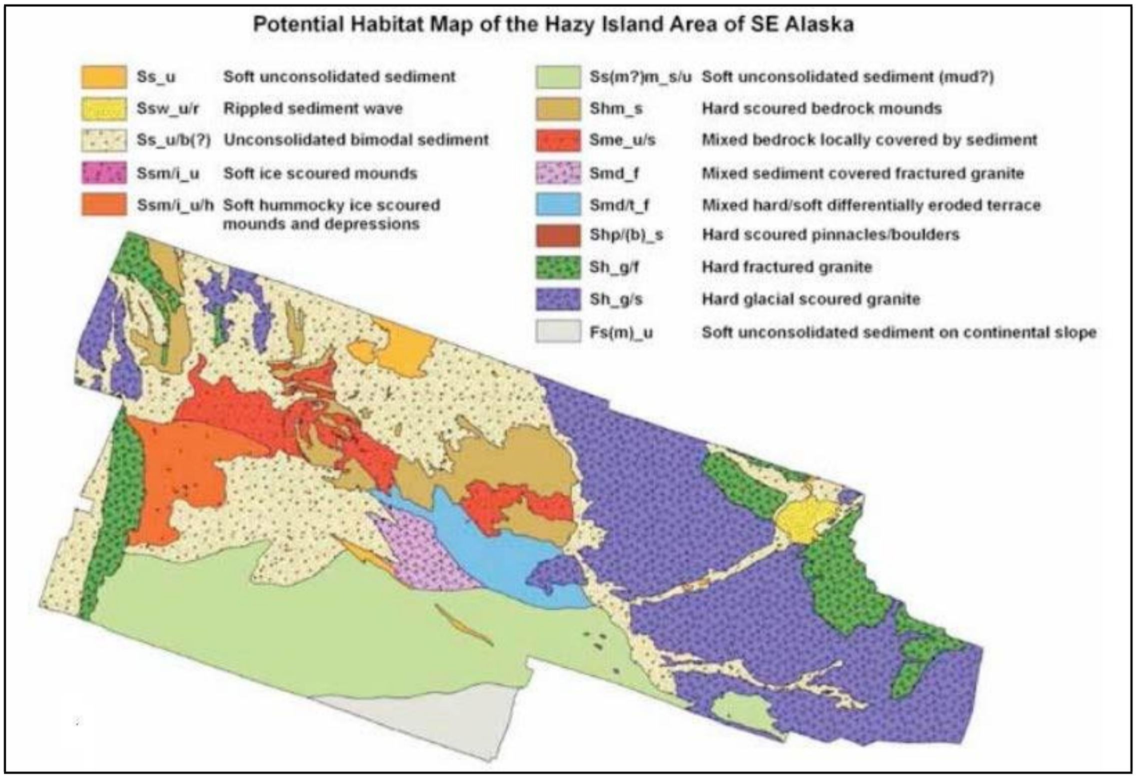


Figure A1 The use of attribute codes on a map of the Hazy Island in SE Alaska (Greene et al. 2007).

2007 – Rapid method to characterize seabed habitats

In another study at Point Harris Marine Reserve just north of the Channel Islands National Marine Sanctuary, Anderson et al. (2007) used a three-tiered visual seafloor characterization including substratum composition, bedform relief, and biota presence. The schema included a two-character notation for primary and secondary substrate by using the first letter of each of the two substrata types, e.g., "SM" for "sandy mud."

Hardness of substrate and vertical relief are incorporated into their substratum composition component as follows:

Substratum	Rock – Exposed bedrock Boulders - >25.5 cm loose material Cobbles - >6.5 cm and <25.5 cm Sand - lighter color, grains visible to naked eye Mud – darker color than sand, grains not visible Coquina – Shell hash, finely broken shell material (~2 mm)
Relief	Flat (0 m) Low relief (<1 m) Moderate relief (1-3 m) High relief (>3 m) Rock walls (high-relief with >80° incline)

Data entry tasks were shared among the observers, and the tasks overlapped, which helped to increase consistency. Each observer entered the data for the previous observer. Overall, they felt their three-tiered method could easily be used to collect and process data to be uploaded to a database. It proved to be useful for determining spatial patterns of biota and correlating them with their habitat preferences (Anderson et al. 2007). However, depending on the purpose and goals of the study, the number or types of variables may need to be reduced (Anderson et al. 2007).

2008 – Video-supervised classification for mapping seafloor habitat

A GIS Seafloor Character Map project off the coast of Santa Barbara, California (Cochrane 2008) also focused on hardness of substrate and vertical relief to describe benthic habitat. It was developed as a raster product from sonar bathymetry and backscatter-intensity (multi-beam data) to describe habitat on a finer scale than previous generalized techniques (Cochrane 2008).

This methodology (Cochrane 2008) used three seafloor classes:

Flat-Soft (fine- to medium-grained sediment)
Mixed (mixed sediment and low-relief rock)
Rugose-Hard (high relief rock and boulder)

These classes are a combination of bottom induration types (soft/mixed/hard) characteristic of Greene et al. (1999), and rugosity calculations (Jenness, 2003). Rugosity, rather than other available values, is used for seafloor complexity in order to differentiate rough substrate from smooth-sloping substrate (Cochrane 2008). Once the substrate has been classified, a depth zone (CDFG 2008) and a slope zone (Greene et al. 1999) are added.

Depth zones (CDFG 2008)
1) Intertidal 2) 0-30 m, 3) 30-100 m, 4) 100-200 m, 5) >200 m

Slope zones (Greene et al. 1999)
1) flat (0-5°), 2) sloping (5-30°), 3) steeply sloping (30-60°), 4) vertical (60- 90°), and 5) overhang (>90°)

Figure A2 shows an example of the execution of Cochrane's methodology used on a map in the California State Waters Map Series.

This method incorporates several important habitat predictors for deep-sea corals: bottom hardness, depth, vertical relief, rugosity, and slope. The technique was found to be very effective for developing GIS products and studying correlations between biological and geological observations (Cochrane 2008). The small number of categories reduces the number of treatments to be replicated, and thus makes this technique useful and efficient for visual field surveys of deep-sea habitat.

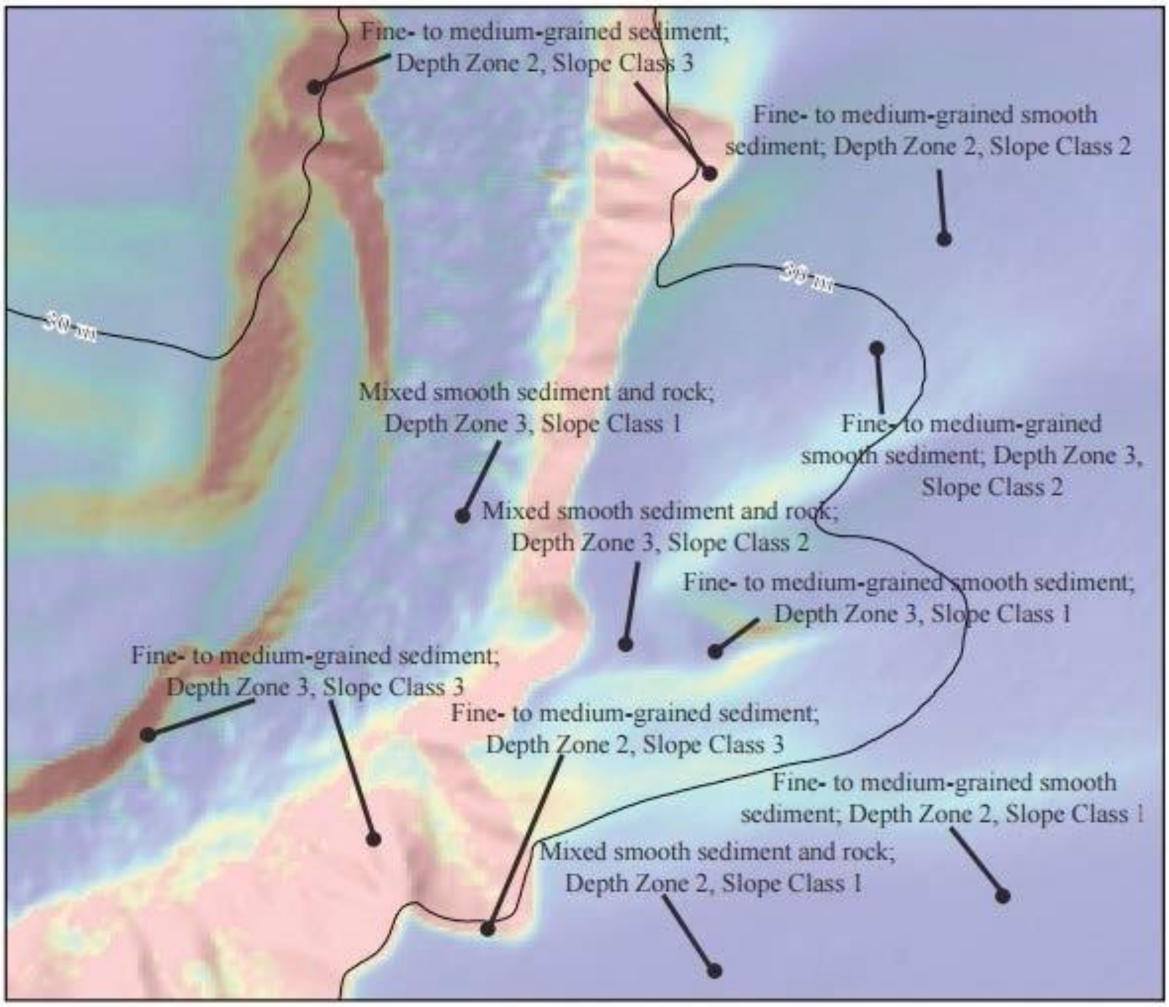


Figure A2 Seafloor Character Map of Hueneme Canyon from Philips and Cochrane, 2012. Rugosity draped over shaded-relief bathymetry. Rugosity values are displayed in muted "rainbow" color spectrum that ranges from purple (low rugosity) through green (medium rugosity)

2009 – Visual surveys in deep water

Yet another seafloor characterization technique was employed in the Southern California Bight in 2009 (Love et al. 2009). In addition to using the substratum types from Greene et al. (1999), this two-letter system indicates primary (≥ 50%) and secondary (≥ 20%) substrate and incorporates vertical relief and hardness of substrate.

The three habitat categories, H (high), L (low), and S (soft), are further qualified by these sub-stratum types: (S) soft sea floor, includes mud (M) and sand (S); (L) low relief includes gravel (G), pebble (P), cobble (C), and continuous flat rock; (H) high relief includes boulder (B), rock ridge(R), and pinnacle top (T).

HH	BB, BR, BT, RR, RB, RT, TT, TB, TR
HL	BG, RG, BP, RP, BC, RC, TG, TP, TC, TF, BF, RF
HS	RS, RM, BS, BM, TS, TM
LH	CB, CR, GB, GR, PB, PR, FB, FR, FT
LL	CC, FC, FF, PP, GG, CF, CG, CP, FP, GC, GP, PC
LS	CS, CM, FS, FM, GS, GM, PS, PM
SH	SR, MR, SB, MB, ST, MT
SL	SC, MC, SG, MG, MF, SF, MP, SP
SS	SS, MM, SM, MS

Appendix B – Notation Format Examples from EX1504 Legs 3 and 4

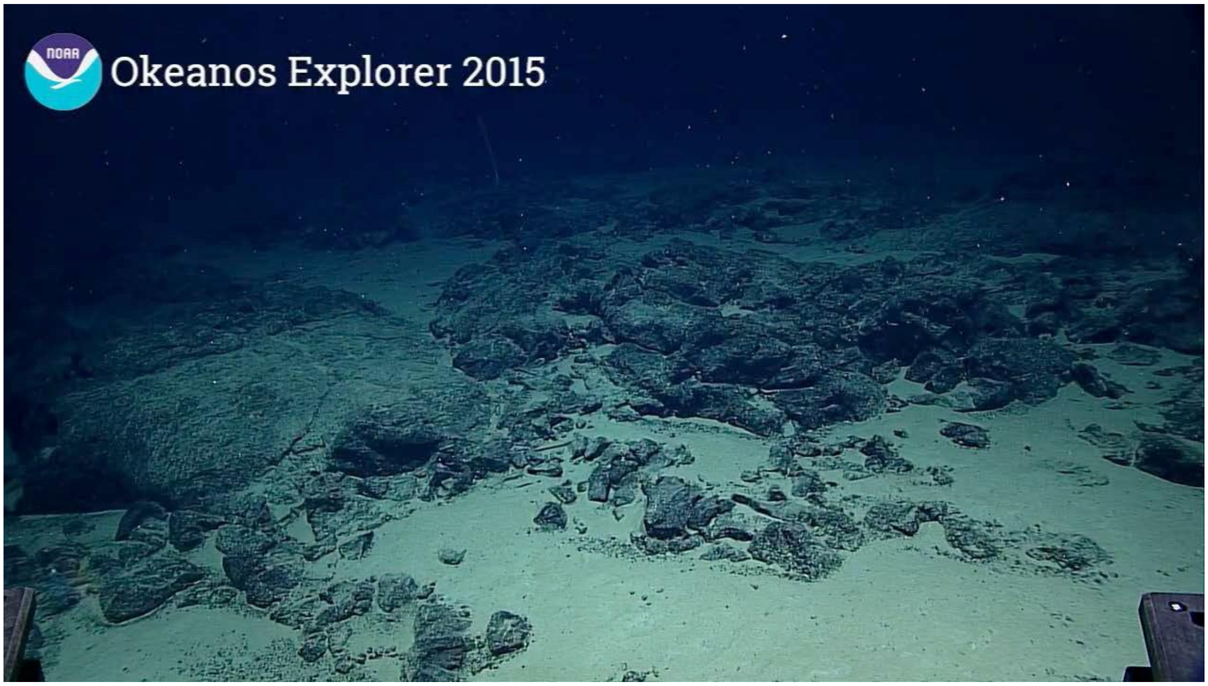


Figure B1 An image of mixed hard and soft substrate from NOAA *Okeanos Explorer* Hohonu Moana 2015 expedition, Leg 3, Dive 04, at 2587-2715 m depth. The image shows Lava Rock as the primary substrate, with Unconsolidated Sediment as the secondary substrate. The CMECSannotation used in theis case was >CMECS Rock/Unc: Lava/SED.

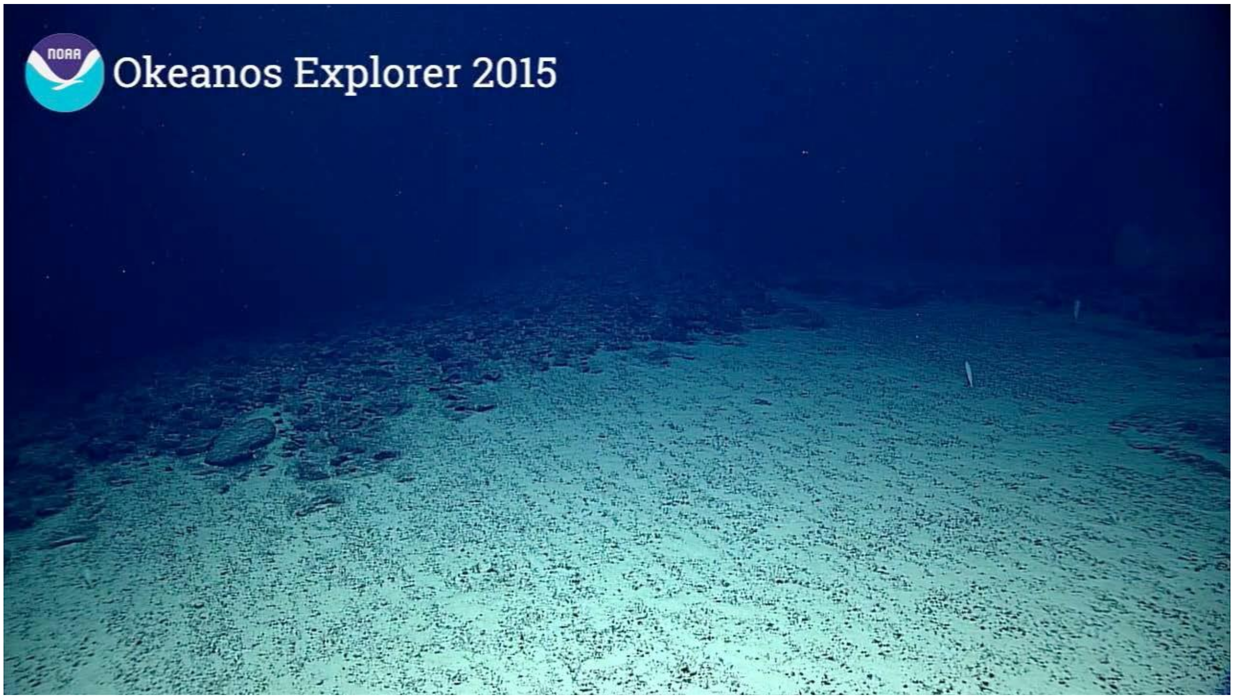


Figure B2 An image of mixed soft substrate from NOAA *Okeanos Explorer* Hohonu Moana 2015 expedition, Leg 3, Dive 04, at 2587-2715 m depth. The image shows Unconsolidated Sediment as the primary substrate, with Unconsolidated Lava Rubble as the secondary substrate. The CMECS annotation used in this case was >CMECS Unc/Unc; SED/RUB lava.

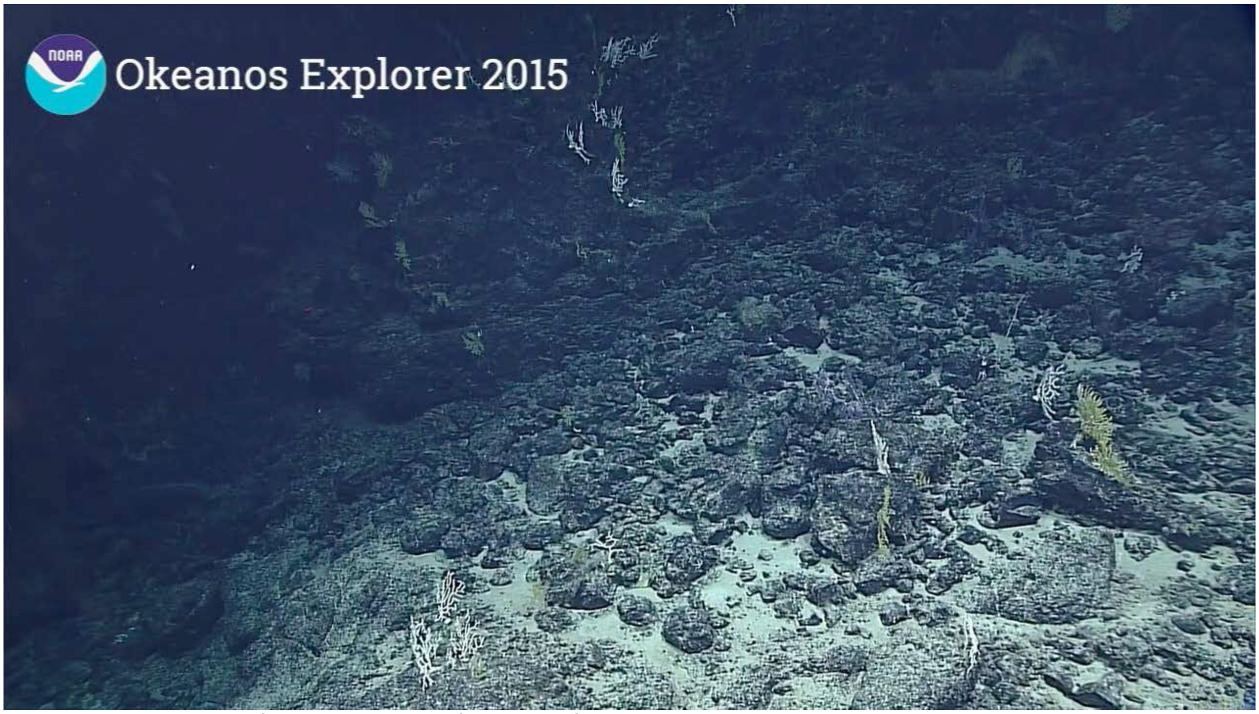


Figure B3 An image of mixed hard and soft substrate from NOAA *Okeanos Explorer* Hohonu Moana 2015 expedition, Leg 3, Dive 05, between 953 and 2638 m depth. The image shows Lava Outcrop and Large Boulders as the primary substrate, with Unconsolidated Light Sediment between the Boulders as the secondary substrate. The CMECS annotation used in this case was >CMECS Rock/Unc; Lava boulders and large outcrop/LIG SED between ROC.

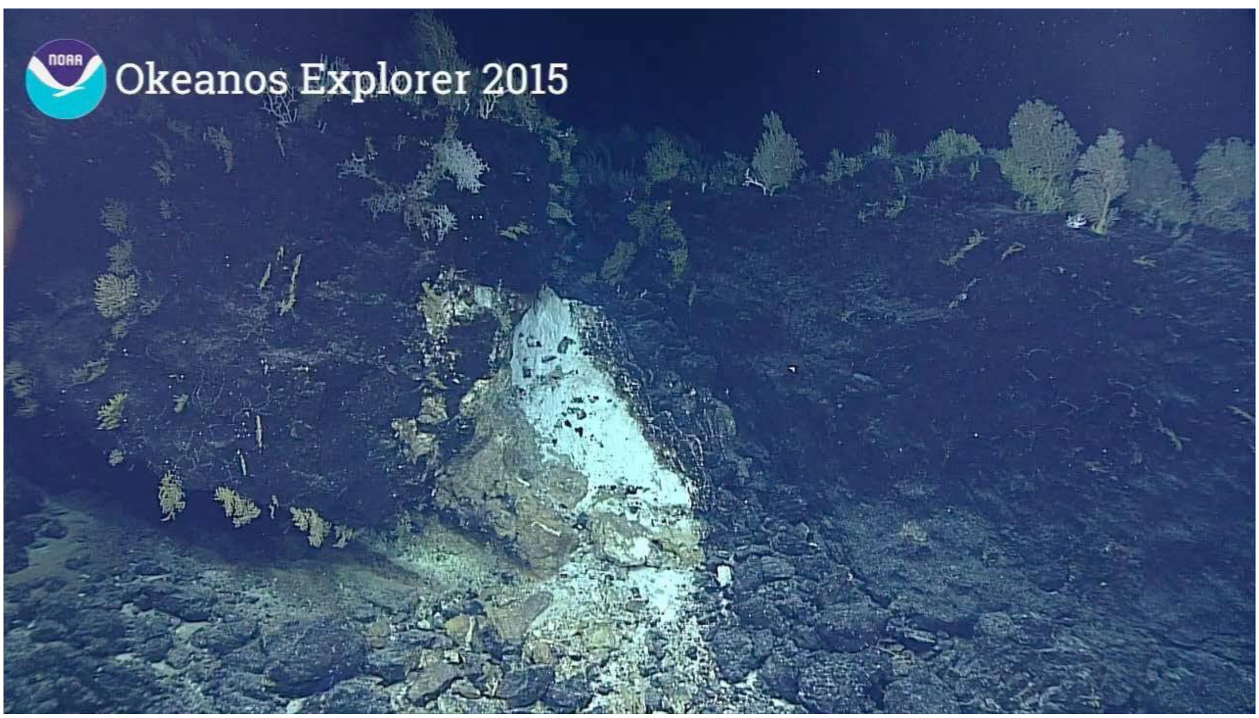


Figure B4 An image of hard substrate from NOAA *Okeanos Explorer* Hohonu Moana 2015 expedition, Leg 3, Dive 05, between 953 and 2638 m depth. The image shows Lava Rock Wall and Slump material as the primary substrate, with no secondary substrate. The CMECS annotation used in this case was>CMECS ROC/NA; Lava WAL and slump.

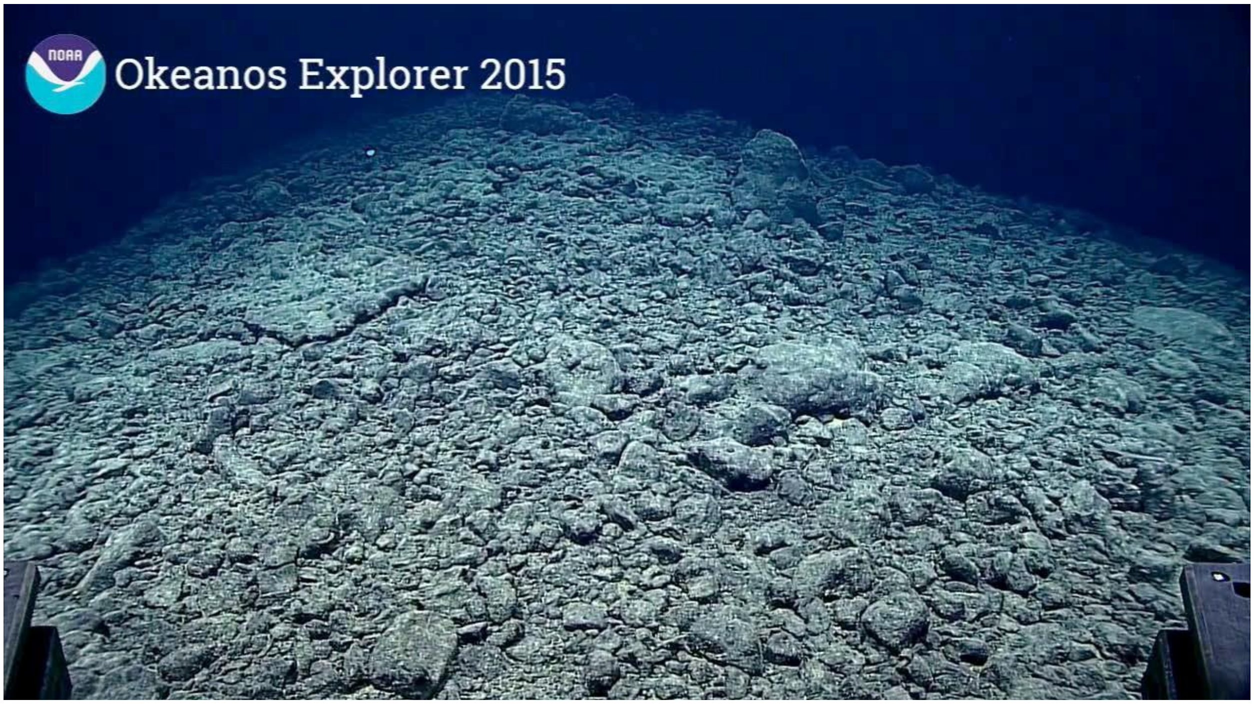


Figure B5 An image of mixed hard substrate from NOAA *Okeanos Explorer* Hohonu Moana 2015 expedition, Leg 4, Dive 12, from 4091-4260 m depth. The image shows Lava Rubble and Medium-sized Cobble as the primary substrate, with no secondary substrate. The CMECS annotation used in this case was >HH lava RUB with medium COB.

Appendix C – Still image Microsoft Access Database Examples - *Shearwater* CINMS SW-15-08

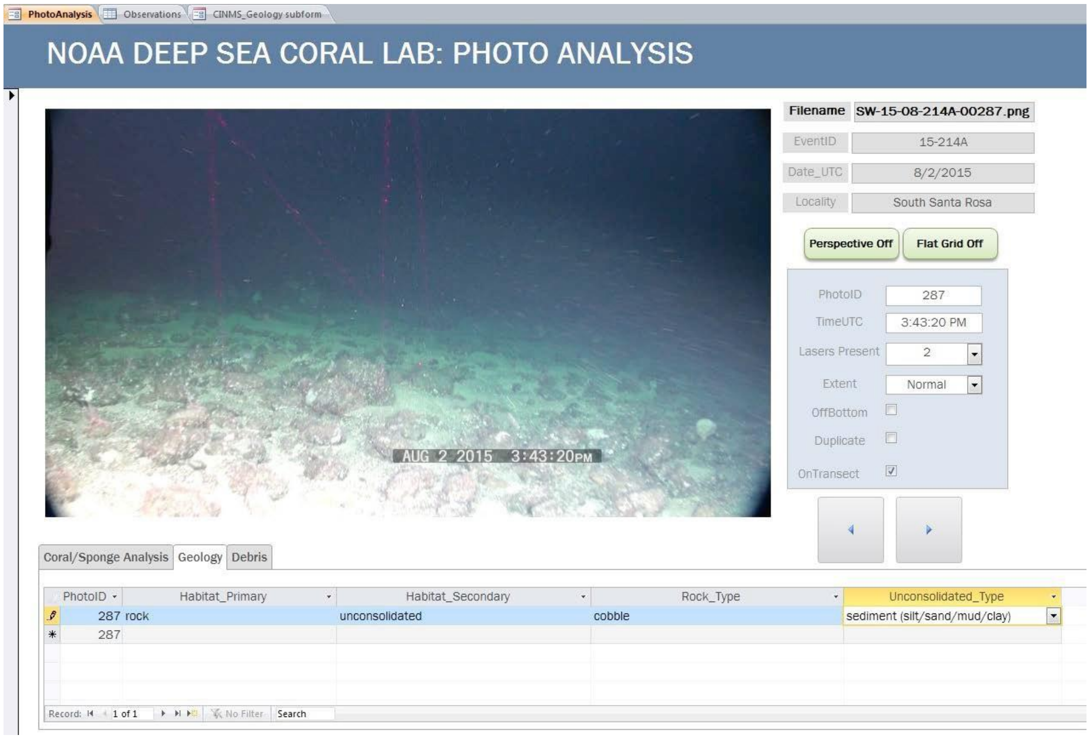


Figure C1 screen grab of the Geology entry screen in Microsoft Access for analysis of still image 287 taken from an ROV dive in the Channel Islands National Marine Sanctuary in August, 2015.

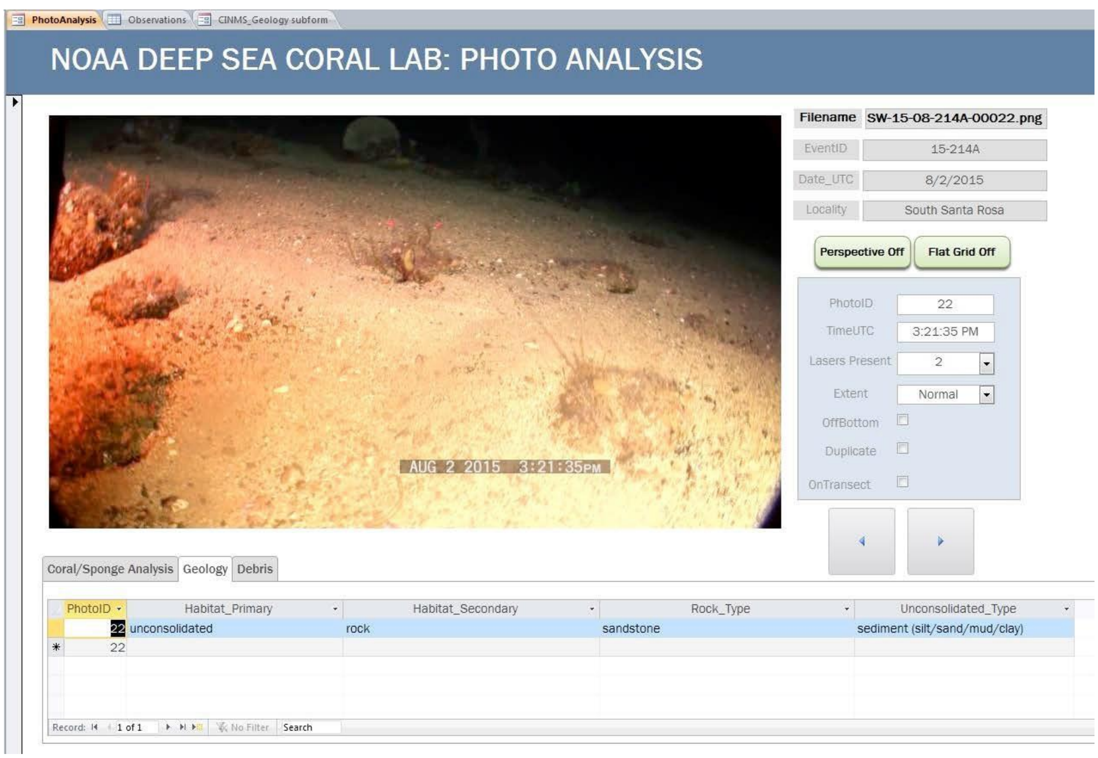


Figure C2 screen grab of the Geology entry screen in Microsoft Access for analysis of still image 22 taken from an ROV dive in the Channel Islands National Marine Sanctuary in August, 2015.

Appendix D – Recommendation Example Images

Following are images from NOAA *Okeanos Explorer* Hohonu Moana 2015 expedition, Legs 3 and 4, showing examples of substrate encountered that does not currently have an OER shorthand code or CMECS unit for visual observation entry.

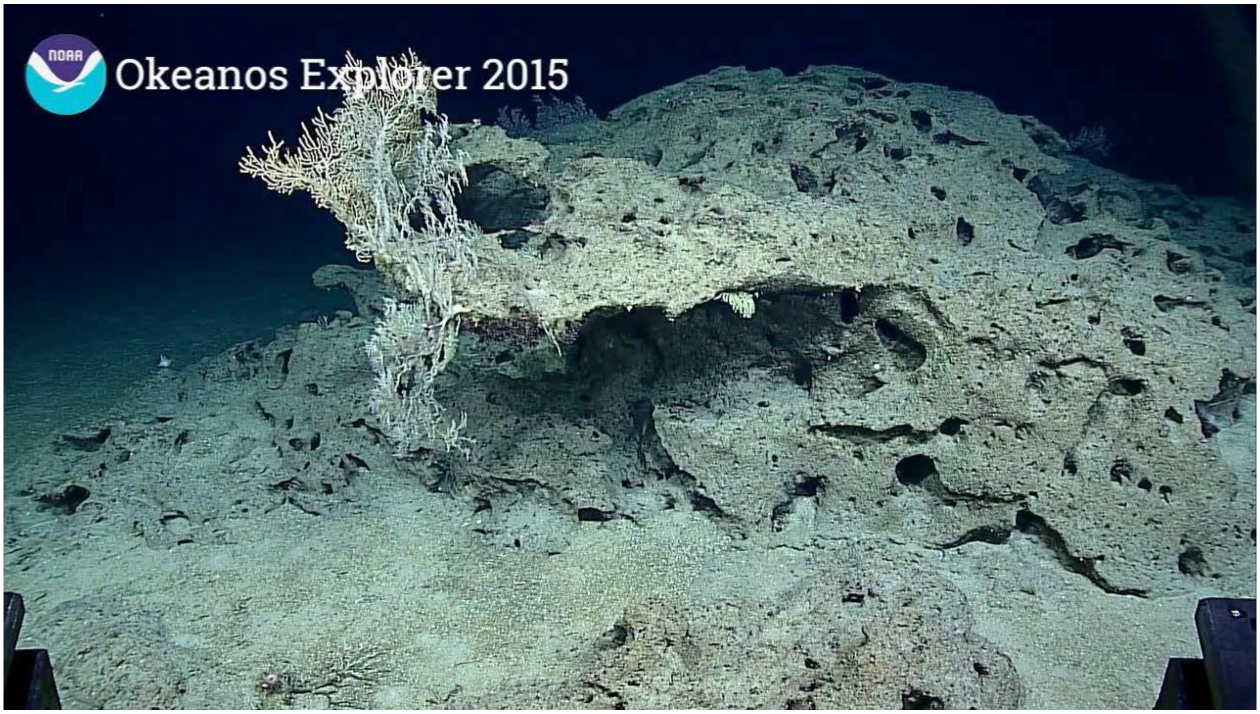


Figure D1 Fossil Reef as substrate for several small corals.

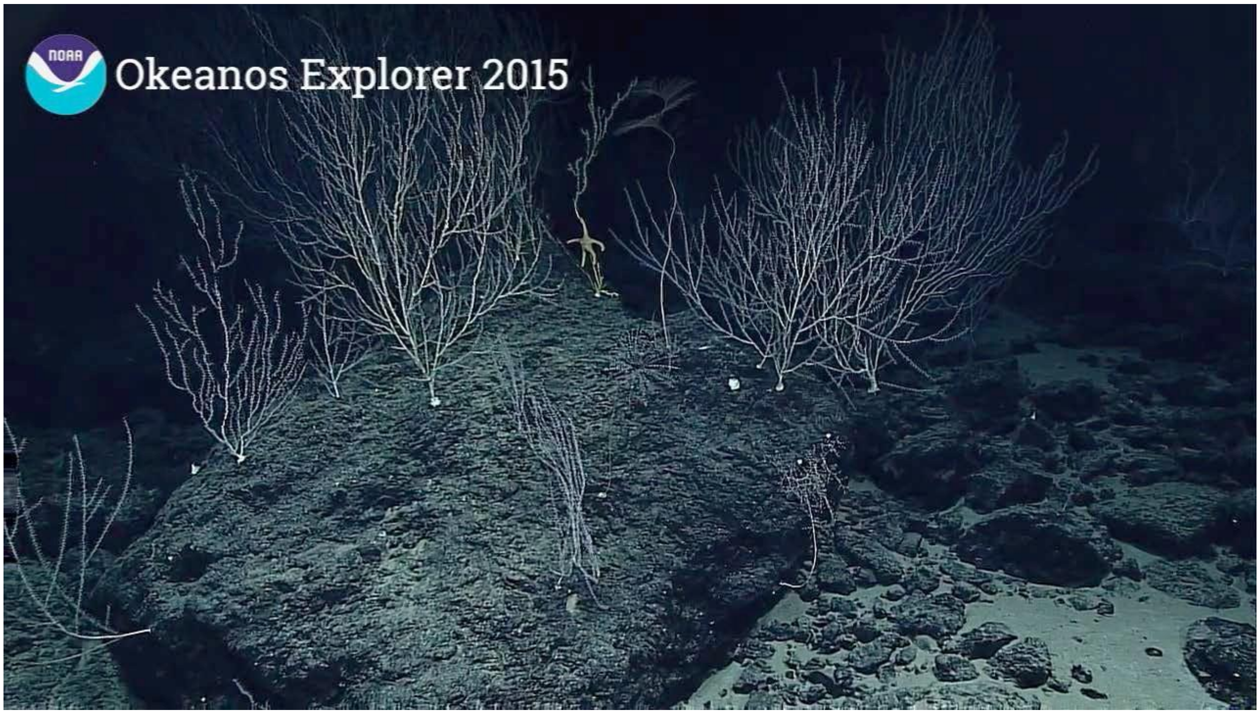


Figure D2 Lava outcrop or boulder. Bamboo corals can be seen growing on the boulders.

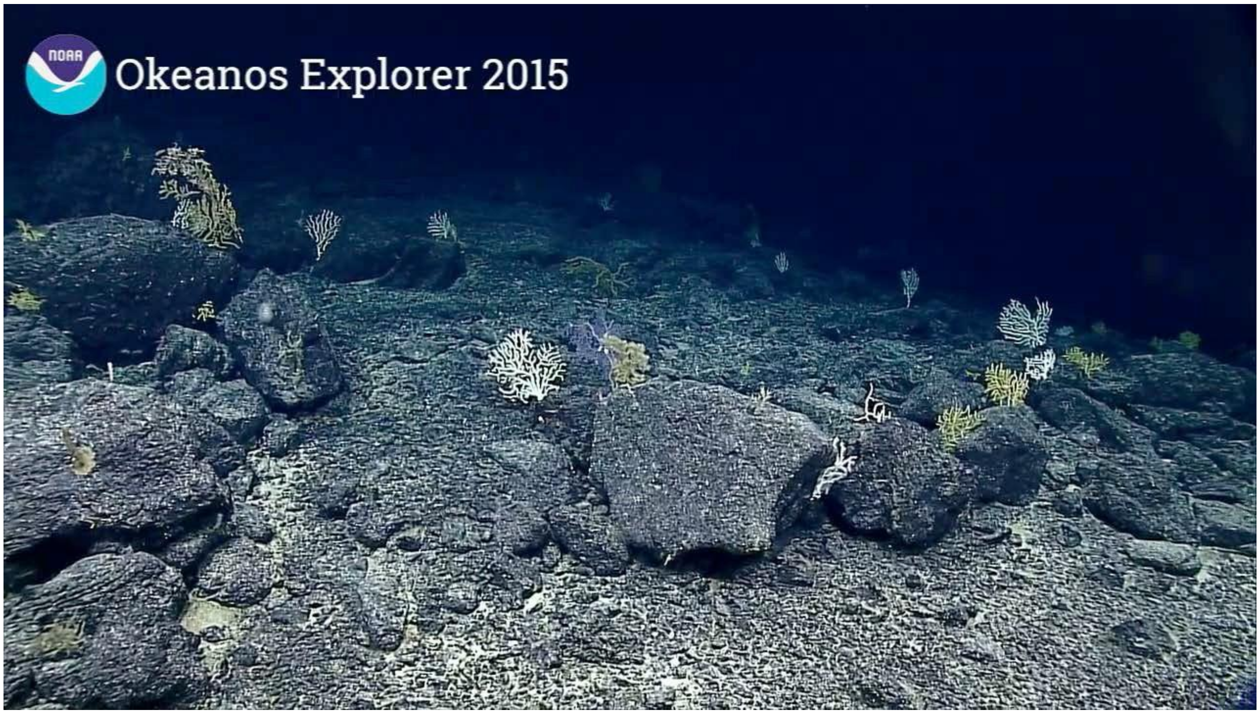


Figure D3 Lava boulders among a community of coral colonies.

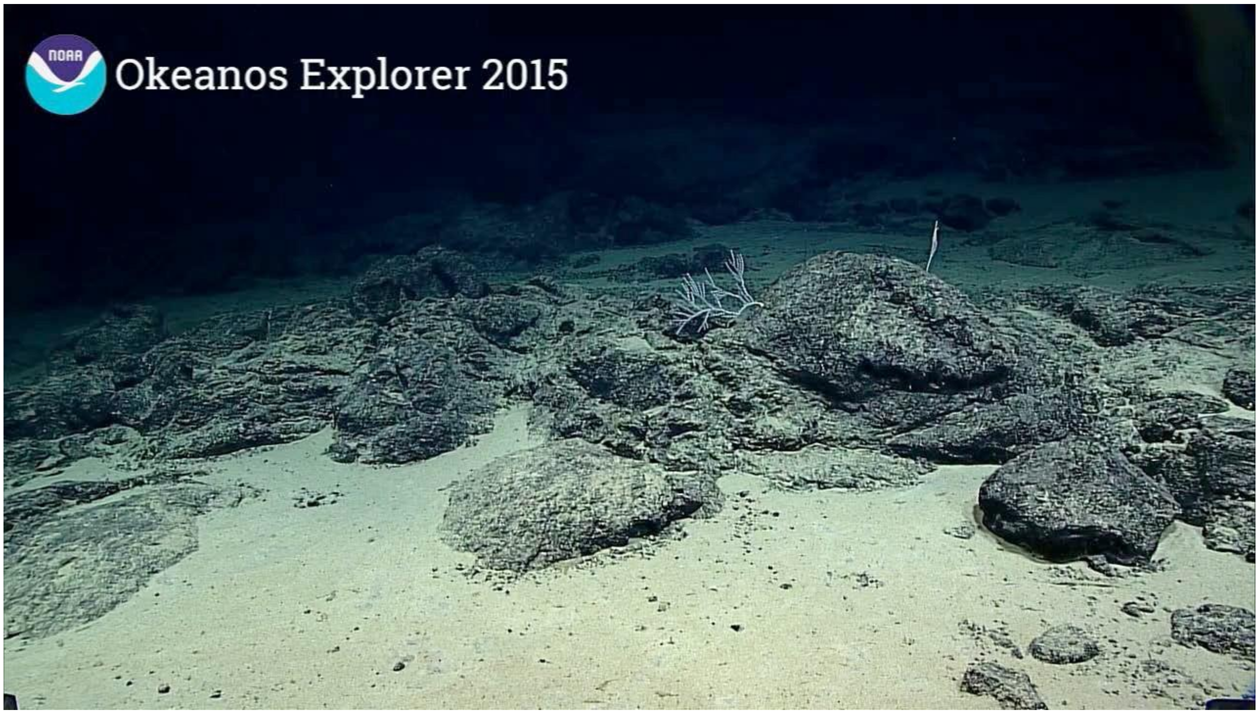


Figure D4 Lava as a Rock type in coral habitat.

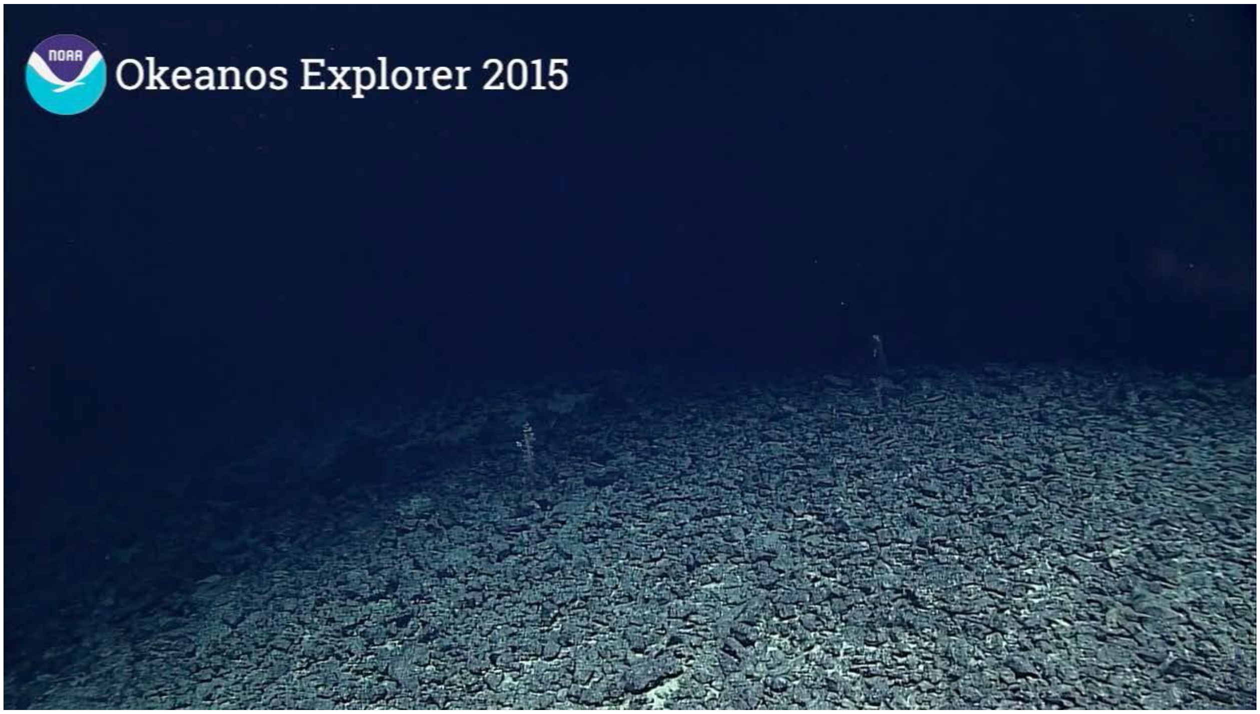


Figure D5 Lava Pebble as unconsolidated substrate.

Figure D6 Lava Gravel as unconsolidated substrate.

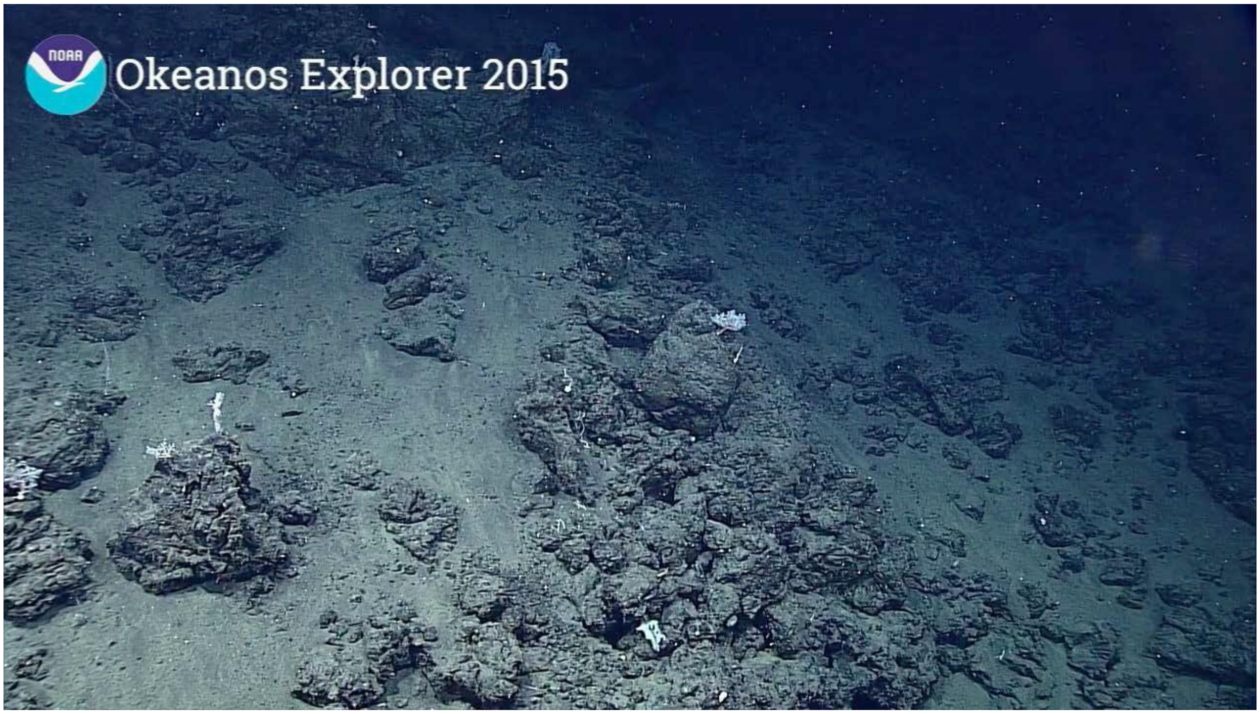


Figure D7 Talus as substrate.

Appendix E – Pre-cruise documents

Figure E1 Page 1 of *Okeanos Explorer* Dive Plan 05 for EX1504L3

Please use this as a template for documenting your recommendations for high---priority dive targets. Be sure to include a rationale for the dive as well as specific protocols (if applicable), and any known previous work or potential hazards at the site. Please include only generalized location information for any marine archaeology sites.
The form also includes fields for mapping targets and CTD cast locations as well. Please send the completed form to *Kelley.Elliott@noaa.gov* *and* ckelley@hawaii.edu

Site Name: Swordfish Seamount

Approximate Location: 18.3124614/---158.4558287

CMECS Geoform: Seamount

Dive Date (local): 2015/09/01

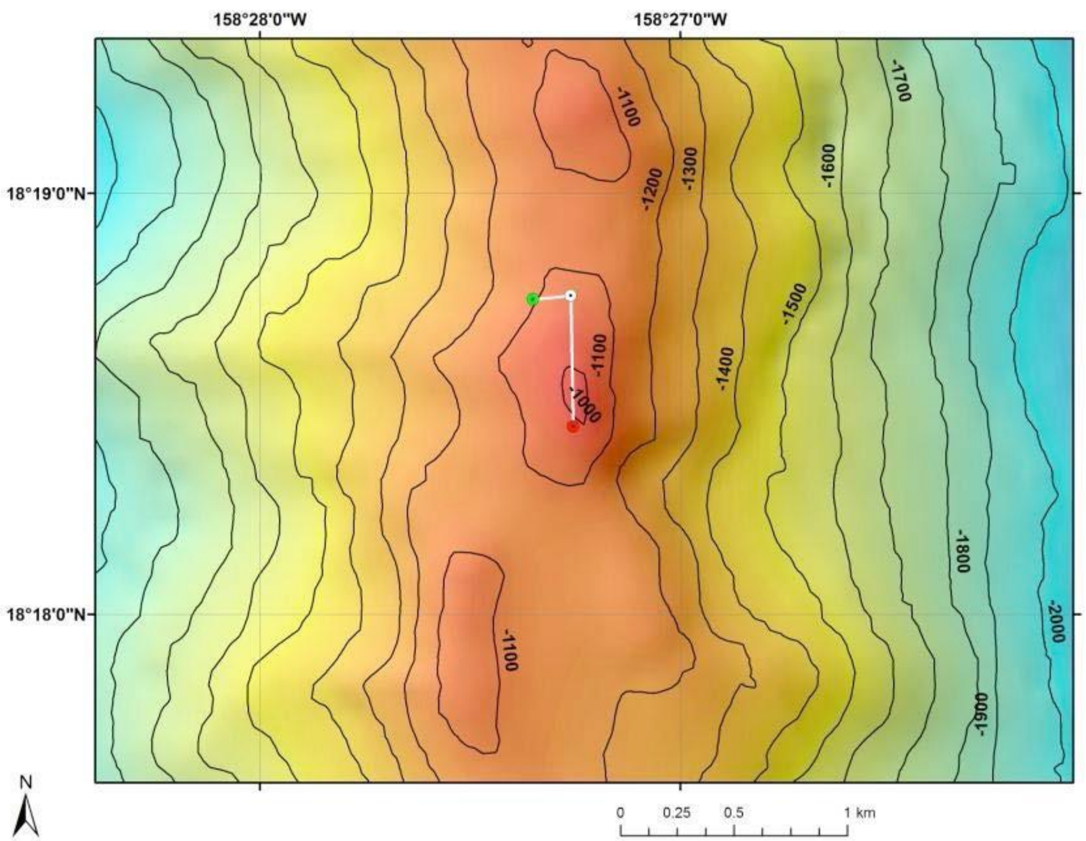


Fig 1: Bathymetry data for the dive site. Dive start and end points are shown as green and red dots, respectively.

Figure E2 *E/V Nautilus* Dive Plan H1451

H1451 Dive Plan

Nautilus Cruise NA066 – Southern California Borderland

Date: August 3, 2015

Lead Scientist: Pete Girguis/Lisa Levin

Dive Site: Redondo Canyon seep

Expedition Leader: Mike Brennan

CMECS Geoform: Bight, Borderland, Basin

Position: 33.799, -118.65

Vital Stats

- Expected launch time: 2000 PDT
- Expected length of dive: 12 hours
- On deck by: 0800 PDT
- Expected depth at launch: 925m

Vehicle Configuration

- Forward Box: 2 partitions
- Front porch: Sample wand with T probe
- Starboard box: 6 partition box
- CTD and Oxygen Optode
- Titanium water sampler
- Slurp Sampler
- Niskin Bottles
- Pushcores (6)
- Mass Spectrometer

Watch

Leaders 8-

12: Lisa

Levin
4-8: Mike Brennan
12-4: Pete Girguis

Dive Plan & Objectives

(1) Visual survey of area associated with the "gas plume" features seen on the multi-beam map made previously by Nautilus. The goal of the visual survey is to find the source of gas emissions from the seafloor. Specifically, we are to conduct a systematic survey of an appropriate area of the seafloor (TBD by watch leaders) to look for:
  a. Gas plumes
  b. Temperature anomalies
  c. Microbial mats associated with gas emissions
  d. Carbonate crusts (squat, sometimes pancake-like, rocks partially buried in the sediments)

(2) If such features are found, we are to conduct our standard sampling suite for exploration includes collecting representative rocks, sediment cores, animals and *in situ* geochemistry

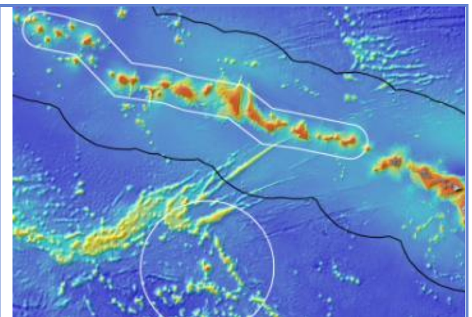
(3) In parallel, you are to be photo surveying wide diversity of sites, capturing video from 1.5 meters or so off bottom, with the laser scales visible in the field of view.

(4) Push cores of sites that represent different ecosystems, sequencing… going from onsite to offsite

(5) Mass spec sniffing as needed

Appendix F – Post-cruise documents

Figure F1 Page 1 of *Okeanos Explorer* Post-Dive Summary from Dive 03 of EX1504L3



Site Name	South Kona transect of 1868 lava flow		
ROV Lead/Expedition Coordinator	Brian Bingham Kelley Elliott		
Science Team Leads	Frank Parrish (Biology) Christopher Kelley (Biology)		
General Area Descriptor	Main Hawaiian Islands	**CMECS Geoform:** Lava Field, Island Slope	
ROV Dive Name	Cruise Season	Leg	Dive Number
	EX1504	3	DIVE03
Equipment Deployed	ROV:	Deep Discoverer	
	Camera Platform:	Seirios	
ROV Measurements	☒ CTD	☒ Depth	☒ Altitude
	☒ Scanning Sonar	☒ USBL Position	☒ Heading
	☒ Pitch	☒ Roll	☒ HD Camera 1
	☒ HD Camera 2	☒ Low Res Cam 1	☒ Low Res Cam 2
	☒ Low Res Cam 3	☒ Low Res Cam 4	☒ Low Res Cam 2
Equipment Malfunctions	N/A		
ROV Dive Summary (From processed ROV data)	Dive Summary: EX1504L3_DIVE03 ^^ In Water at: 2015-08-30T18:59:35.515000 18°, 57.592' N ; 155°, 43.940' W Out Water at: 2015-08-31T02:27:22.250000 18°, 56.614' N ; 155°, 42.752' W Off Bottom at: 2015-08-31T02:11:38.890000 18°, 56.741' N ; 155°, 42.804' W On Bottom at: 2015-08-30T19:17:36.187000 18°, 57.535' N ; 155°, 43.901' W Dive duration: 7:27:46 Bottom Time: 6:54:2 Max. depth: 454.9 m		
Special Notes			
Scientists Involved ***(please provide name / location / affiliation / email)***	Frank Parrish, EX, PIFSC/PSD, Frank.Parrish@noaa.gov Chris Kelley, EX, UH, ckelley@hawaii.edu Amy Baco-Taylor, FL, FSU, abacotaylor@fsu.edu Asako Matsumoto, Japan, CIT, amatsu@gorgonian.jp Chris Mah, DC, SI, mahch@si.edu Michael Parke, HI, PIFSC, Michael.Parke@noaa.gov Nicole Morgan, FL, FSU, nbmorgan11@gmail.com Scott France, LA, ULL, france@louisiana.edu Tina Molodtsova, Portugal, PPSIO, tina@ocean.ru Rachel Bassett, SC, CCEHBR, Rachel.bassett@noaa.gov Jonathan Tree, UH ECC, UH, jtree@hawaii.edu Daniel Wagner, UH, PMNM, daniel.wagner@noaa.gov Sam Kahng, UH ECC, HPU Skahng@HPU.edu Meagan Putts, UH ECC, HPU, Mputts@HPU.edu		

Figure F2 *E/V Nautilus* Post-Dive Dive Report from Dive H1447

NAUTILUS DIVE REPORT

Cruise: NA066 **Vehicle:** Hercules / Argus
Lowering ID: H1447 **Site:** Rosebud Whalefall
Launch Time UTC: 31 JUL 2015, 23:17:17 **Recovery Time UTC:** 1 AUG 2015, 07:22:33
On Bottom Time UTC: 1 AUG 2015, 00:17:42 **Off Bottom Time UTC:** 1 AUG 2015, 06:17:28

Latitude: *On Bottom*: 32.7760495149 *Off Bottom:* 32.7754885183N
Longitude: *On Bottom*: 117.487847881W *Off Bottom:* 117.486649133W
Vehicle Depth: *On Bottom:* 837.24m *Off Bottom:* 824.06m

Samples: NA066-043, NA066-044, NA066-045, NA066-046, NA066-047, NA066-048, NA066-049, NA066-050, NA066-051, NA066-052, NA066-053, NA066-054, NA066-055, NA066-056, NA066-057.

CMECS Geoform: Bight, Borderland, Whalefall

Dive Summary:
Objective: The goal of the dive is to observe the whale fall Rosebud, which was purposefully sunk a few years prior. Observation will be mostly visual, but some minimally invasive samples will be taken.

23:17 – 00:17 Vehicles in water, krill, skinny fish, squid, on bottom.
00:17 – 00:38 Landed on bottom away from whale. Sea stars, anemones, rock fish and sponges. Moving along bottom to get to whale. Stalked sponges with epispongal anemones. Red jelly, sea pens, thornyheads, holothurian, stalked crinoids, large siphonophore. Whale skeleton becomes visible.
00:38 – 01:08 Marine snow is dense, O_2 is 6.8. Hercules circling skeleton to get good views; thornyheads using bones as shelter and anemones on a line. Bacteria visible on bone. Photo mosaics taken from tail to head, and head to tail on both sides. White bacterial mat between jaws. Flatfish also seen.
01:08 – 01:30 Zooming on bottom jaw; thornyhead, scale worms visible. Amphoretids maybe living in bacterial mat. Osedax spotted on lower jaw. Snails and brittle stars on sediment, and a galatheid crab on a sponge stalk. Fish may be hiding in skeleton.
01:30 – 02:00 Camera pan and close ups of the vertebrae. Black, white and brown bacteria visible; tuna crab carcasses scattered along, probably fallen from above. Down along the tail. More urchins and bigger crabs on rope than around bones.
02:00 – 02:30 Holothurians aggregating around the jaw. Preparation to take mass spec.
02:30 – 03:14 Mass spec readings taken above gray mat; sulphides found but little methane. Mass spec over white mat, which has long worms and a few scale worms. Sulfides higher above mats than near osedax. Mass spec reading taken over mid vertebrae with osedax. Mass spec away.
03:14 – 03:37 Sablefish resting by skeleton may be having breathing problem. Push cores taken in the white mat by the central abdomen (NA066-043, 3:20-3:21) and in the grey mat adjacent (NA066-044, 3:22-3:22). Suction samples taken in the grey mat (NA066-045, 03:28- 03:30) and in the surface of the white mat (NA066-046, 03:32-03:34). Moved toward the head.
03:37 – 04:12 2-lined eelpout seen. Slurp of lower right jaw bone to get scale worms and others (NA066-047, 03:50-03:53). Many push core attempts, and a successful core of the ampharetid sediment by the jaw (NA066-048, 04:09-04:10). Snail fish seen during the tries.
04:12 – 04:40 Zoom on a thornyhead. Ossidax visible on the jaw. Mass spec taken on the bacterial mat by the jaw. Close up of scale worms on the lower jaw. Sat on bottom. Mass spec the jaw reads higher oxygen and lower sulfide. Different species of ossidax seen on upper jaw.
04:40 – 04:57 Suction of the ampharetid beds by the lower right jaw (NA066-049, 04:44- 04:46). Niskin fired above bottom next to Rosebud (NA066-050, 04:51-04:51). Moving upslope to get cores; anemones and sponges visible again.
04:57 – 05:07 Stopped about 15m from whale. Push core taken (NA066-051, 05:03- 05:06).
05:07 – 05:30 Core dropped and retrieved over time.
05:30 – 05:49 Five niskins fired (NA066-052, 05:39-05:39; NA066-053, 05:40-05:40; NA066-054, 05:40-05:40; NA066-055, 05:40-05:40; NA066-056, 05:40-05:40). Suction of soft sediment bottom (NA066-057, 05:47-05:48).
05:49 – 06:08 Driving upslope to survey the bottom with lasers on. Red jelly, small thornyheads and lots of suspension feeders, including hydrozoans, anemones, sponges and sea pens. Paused over anemones, hydrozoan, thornyhead and sponges. Many anemones on sponges, small sea pens, hydrozoans and small thornyheads. Two flatfish and a hagfish.
06:08 – 06:17 Snailfish seen by Argus. A few crabs. Off bottom.
06:17 – 07:22 Squid inked as it passed by Argus. Passed by pelagic crabs. Bubbles emerging from push cores. Vehicles on deck.

Figure F3 *E/V Nautilus* Post-Cruise Dive Log for California Borderlands Cruise NA066

Dive	CMECS Geoform	CMECS Water Component	Start YYYY	Start Mm	Start Dd	Start Time (UTC)	End Yyyy	End Mm	End Dd	End Time (UTC)	*Total Time*	On bottom Time	Off Bottom Time	*Total Bottom time*
NA066 California Borderlands														
H1444	Bight, Borderland	Seep, Bathybenthic	2015	7	27	23:11:23	2015	7	28	16:08:13	**16:56:50**	00:08:13	14:25:09	**14:16:56**
H1445	Bight, Borderland	Seep, Bathybenthic	2015	7	28	19:39:13	2015	7	29	03:40:48	**8:01:35**	20:30:56	02:35:05	**6:04:09**
H1446	Bight, Borderland, Open Upper Slope	Mesobenthic	2015	7	29	15:15:50	2015	7	29	18:47:48	**3:31:58**	15:40:44	18:13:06	**2:32:22**
H1447	Bight, Borderland, Whalefall	Mesobenthic	2015	7	31	23:17:17	2015	8	1	07:22:33	**8:05:16**	00:17:42	06:17:28	**5:59:46**
H1448	Bight, Borderland	Seep, Mesobenthic	2015	8	1	11:03:14	2015	8	2	03:08:33	**16:05:19**	11:44:56	02:24:23	**14:39:27**
H1449	Bight, Borderland, Submarine Fan, Mouth of Canyon	Mesobenthic	2015	8	2	07:18:56	2015	8	2	18:08:07	**10:49:11**	07:49:37	17:16:45	**9:27:08**
H1450	Bight, Borderland	Mesobenthic	2015	8	3	01:08:12	2015	8	3	07:19:01	**6:10:49**	01:52:19	06:01:29	**4:09:10**

United States Department of Commerce
Wilbur Ross
Secretary of Commerce

National Oceanic and Atmospheric Administration
Benjamin Friedman
Deputy Under Secretary for Operations and Acting Administrator

National Ocean Service
Russell Callender
Assistant Administrator