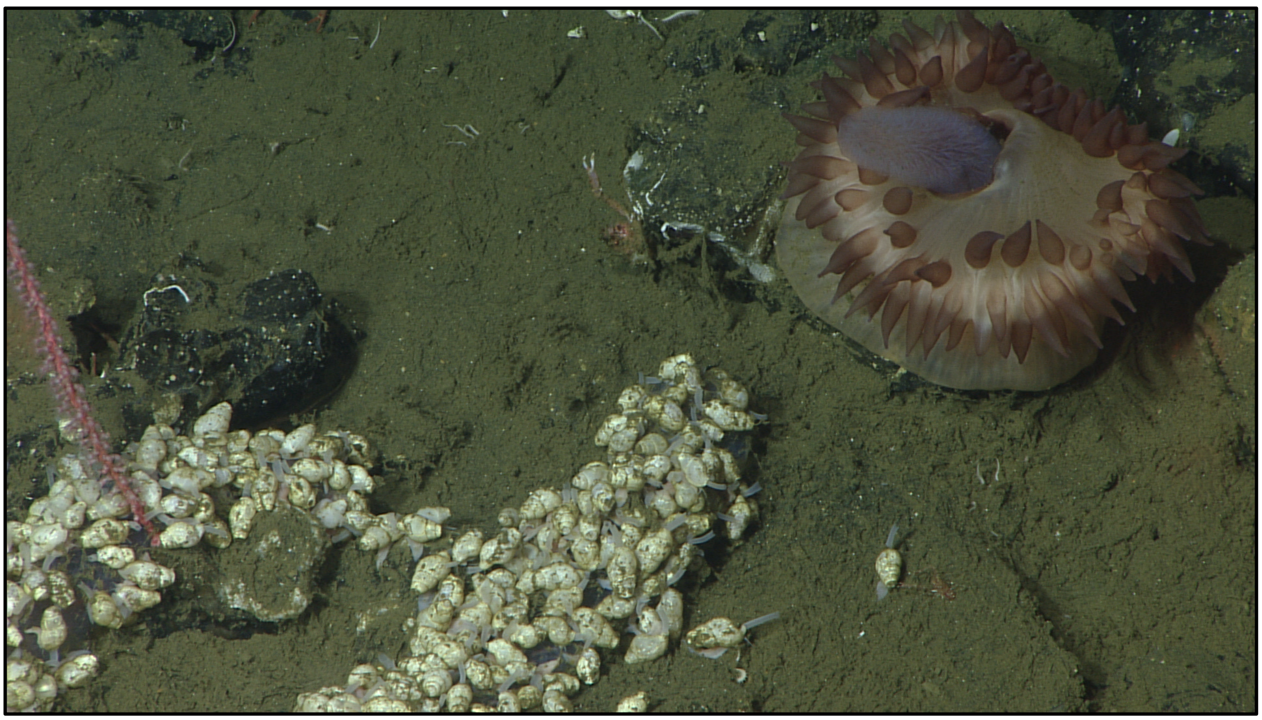
OCS Study
BOEM 2021-037

California Deepwater Investigations and Groundtruthing (Cal DIG) I, Volume 1: Biological Site Characterization Offshore Morro Bay



US Department of the Interior
Bureau of Ocean Energy Management
Pacific OCS Region

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California Deepwater Investigations and Groundtruthing (Cal DIG) I, Volume 1: Biological Site Characterization Offshore Morro Bay

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US Department of the Interior
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DISCLAIMER

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ABOUT THE COVER

Stylaster californicus with a Blacksmith (*Chromis punctipinnis*).

ACKNOWLEDGMENTS

We thank the science parties of the cruises discussed in this report and the remotely operated vehicle (ROV) pilots aboard the *R/V Bold Horizon*, Dale Graves, Frank Flores, and Lonny Lundsten. We thank the crew of the *R/V Western Flyer* and *Doc Ricketts* ROV pilots as well. Eve Lundsten provided the bathymetry and the location of pockmarks. Tony Phillips and Dean Lasko identified infaunal specimens for the project and Lonny Lundsten and Larissa Lemon provided valuable Monterey Bay Aquarium Research Institute (MBARI) video lab support. This study was funded by the Bureau of Ocean Energy Management under Intra-Agency Agreement M17PG00021 with the US Geological Survey (GAC1900041) and the David and Lucile Packard Foundation (MBARI Project 706004).

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List of Abbreviations and Acronyms

ANOVA	Analysis of variance
BOEM	Bureau of Ocean Energy Management
Cal DIG I	California Deepwater Investigations and Groundtruthing I
CMECS	Coastal and Marine Ecological Classification Standards
EFH	Essential Fish Habitat
EXPRESS	Expanding Pacific Research and Exploration of Submerged Systems campaign
GPS	Global positioning system
HAPC	Habitat Area of Particular Concern
HSD	Honestly significant difference
MARS	Monterey Accelerated Research System
MBARI	Monterey Bay Aquarium Research Institute
MBES	Multibeam Echo Sounder
NOAA	National Oceanic and Atmospheric Administration
OMZ	Oxygen minimum zone
ROV	Remotely operated vehicle
R/V	Research Vessel
SIMPER	Similarity percentage
SIMPROF	Similarity profile routine
US	United States
USGS	US Geological Survey
VARS	Video Annotation and Reference System from MBARI
USBL	Ultra short base line

Executive Summary

An integrated regional understanding of geophysics and biology are critical for comprehensive marine planning. Yet as of 2017, the US Federal seafloor off central California was unmapped using modern methods and largely unsampled. A partnership called the Expanding Pacific Research and Exploration of Submerged Systems focused on a biological and geological characterization of the area offshore Morro Bay, California from 2017 to 2019. Subsequent reports by the US Geological Survey will describe the geophysical, geotechnical, and habitat mapping results. This report describes the biological characterization on the seafloor lead by the Monterrey Bay Aquarium Research Institute, conducting 40 remotely operated vehicle dives from 371 to 1173 meters. Seafloor habitats and megafauna (fish and invertebrates) were observed across 46.8 km of the seafloor. Biological communities were compared using 18.52 km^2 of subsampled linear benthic transect video. From 185 hours of observational and quantitative transects at 25 sites, nearly 120,000 annotations of organisms and their habitat were created. The primary habitat observed was soft substratum (80 %) and bedrock constituted 3.2 % of the area surveyed. Within the soft substrata is a ~1300 km^2 area containing several thousands of seafloor depressions called pockmarks. Two pockmarks were selected for additional sampling to determine if biological communities (megafauna and infauna) inside individual pockmarks significantly differ from those outside the pockmarks. Substrata were binned into soft, pockmark fields, and mixed/hard habitat for analysis across a range of depths. Over 101,000 megafaunal organisms were observed in video representing an equal split of 35 % predator/scavengers, 34 % surface deposit feeders, and 30 % suspension/filter feeders. Abundant biological detritus, in the form of dead and dying pyrosomes and salps, represented a large flux of carbon to the seafloor. We conducted 97 quantitative transect video surveys at 13 sites finding 173 taxa with a species richness ranging from 8–55 taxa. Densities ranging from 0.07 to 5.2 m^{-2} decreased with depth and among substrate groups. Seventy percent of the transects occurred inside the oxygen minimum zone and we conclude the presence of hard substratum was a better predictor of species richness and density than oxygen concentration. Overall, transects within the depth vs. substratum categories were less than 40 % similar in multivariate analyses based on cluster analysis. We used the distinct (dissimilar) biotic clusters to create and describe 18 biotopes. Biotope analysis allowed us to explain habitat associations using finer depth and substratum categories. For instance, mud containing coarse sand occurred only in very low oxygen areas and supported unique biologic assemblages, while hummocky mud supported somewhat different species than flat mud plains. We hypothesized the soft substrate pockmark fields would be a distinct biotope, however, 33 megafauna and 29 infauna taxa were observed in and around pockmarks with no significant differences of density nor species richness at either of the two sites. The biotic associations to seafloor features and substrates can inform future marine planning decisions. If wind turbine development continues for this area, these data can inform the selection of appropriate reference areas and survey designs for impact-related studies.

1 Introduction

1.1 Background

An integrated regional understanding of geophysics and biology are critical for comprehensive ocean planning. US Federal waters on the continental shelf have ongoing efforts by multiple jurisdictions to address marine planning for commercial fishing, conservation, telecommunication cables, mineral extraction, and energy development. Laws and designations (e.g., Habitats of Particular Concern) specifically state the importance of benthic habitats. Conservation of marine resources in the National Marine Sanctuaries covers 13,000 square miles of the seafloor on the US West Coast, and the Outer Continental Shelf Lands Act states the need to characterize and monitor habitats in areas potentially impacted by energy and mineral development. These distinct yet overlapping planning efforts all need extensive biological, geophysical, and geotechnical data at a regional scale in order to assess regional seafloor habitats and hazards to structural engineering. The US West Coast continental shelf and upper slope, despite its many users, had many areas unmapped with modern methods and unsampled. Therefore, there was a need to collect seafloor data, particularly in water depths greater than 400 meters.

The Expanding Pacific Research and Exploration of Submerged Systems campaign (EXPRESS; https://www.usgs.gov/centers/pcmsc/science/express-expanding-pacific-research-and-exploration-submerged-systems?qt-science_center_objects=0#qt-science_center_objects) was formed in 2017 to support data collection offshore of Washington, Oregon, and California. EXPRESS is a collaboration coordinating assets and people across US Federal, state, and private groups to address seafloor and ocean related science needs more effectively. As members of EXPRESS, the Bureau of Ocean Energy Management (BOEM), US Geological Survey, National Oceanic and Atmospheric Administration (NOAA), and Monterey Bay Aquarium Research Institute (MBARI) focused on biological and geological characterizations of the area offshore Morro Bay in central California. This focused project effort of the seafloor offshore central California is called California Deepwater Investigations and Groundtruthing I (Cal DIG I; Figure 1). Offshore central California, Monterey submarine canyon (Greene et al. 1998) and State waters are well described (Johnson et al. 2017). Offshore waters near Morro Bay were chosen as the focus area because of the large gaps in modern seafloor mapping data and the State of California is actively engaged with the BOEM in planning for the possible siting of commercial offshore floating wind projects. BOEM made a call for commercial interest in two regions offshore central California in 400–1200 m water depths (Figure 1). Geological and biological surveys using modern methods were needed for the BOEM to evaluate the potential direct and indirect impacts to marine environments.

Surface ship multibeam bathymetric surveys were conducted by NOAA, US Geological Survey, Scripps Institution of Oceanography, and Schmidt Ocean Institute between 2017 and 2019, which now covers most of the seafloor offshore of central California (Figure 1). Geophysical analysis, geotechnical samples, and habitat mapping from the EXPRESS Cal DIG I project will be described by US Geological Survey in subsequent reports however, the preliminary bathymetry and backscatter data were used in this report and critical for the sampling design. The bathymetry shows areas of both low and high relief bottoms. The high relief areas explored in this study, such as Santa Lucia Bank and other topographic highs, contain both rock outcrops (i.e., bedrock) and boulders intermingled with sandy fill (Walton et al. 2020). Two predominately mud filled submarine channel systems, or shallow canyons (Lucia Chica and San Simeon), were also explored (Maier et al. 2011, 2012, 2013, Dobbs et al. 2020, Walton et al. 2021, in prep.). However, the dominate geologic habitat in the study area is characterized by low relief soft substratum. Within the soft substrata is a ~1300 km^2 area containing several thousands of seafloor depressions called pockmarks, which average 175 m in diameter and five meters deep (Lundsten et al. 2019, Paull et al. 2002, 2020). Searches were specifically made for chemosynthetic communities within the pockmarks, and throughout the study area, which could indicate active methane seepage.

The seafloor region offshore Morro Bay has multiple exposures to anthropogenic disturbances with the largest being a major telecommunications cable landing region for the US West Coast. Although applicants must survey and report to the State of California when removing or adding a cable, data are not publicly available. One study on electrified cables showed negligible impacts in shallower water to the south (Love et al. 2017). Only one regional cable laid to the north in the Monterey Bay National Marine Sanctuary (for the National Science Foundation-funded Monterey Bay Accelerated Research System (MARS) has been well studied from the nearshore to deep bathyal depths (Kuhnz et al. 2020a). Commercial fishing occurred in this area and the impact from bottom trawling gear was studied in the more actively fished shallower waters of this region (Lindholm et al. 2015). Oil and gas platforms occur outside the study area to the south and closer to shore. Impacts from platform discharges were studied at three platforms to the south offshore Point Arguello, California from 1986 to 1995 detecting changes in some species from discharges up to 3 km away (Lissner 1993, Coats 1994, Hyland et al. 1994). Anchor impacts from platform construction were present years later (Lissner et al. 1991, Diener 1995).

Both modern seafloor mapping data and an understanding of the anthropogenic impacts to a region provides context for defining the biological communities associated with the seafloor. Previous biological investigations to the north (Tissot et al. 2008, Lindholm 2009, Hallenbeck et al. 2012) and south (Huff et al. 2013, Shester et al. 2017) of the study region show a relatively higher diversity of megafaunal species (i.e., fish and invertebrates associated with the seafloor or benthos) associated with high relief features such as slope reefs and canyons (Yoklavich et al. 2000), as compared to surrounding continental slope soft substratum habitats. More broadly across the California Current, deep-water fish distributions have been explored (as reviewed in Love and Yoklavich 2006, PMFC 2013) with recent emphasis on commercial fish juvenile habitats (Tolimieri et al. 2020). Deep sea corals and sponge locations were mapped along the US West Coast as an important habitat feature for fisheries (Hourigan et al. 2017, Whitmire et al. 2017, Poti et al. 2020). Efforts to map biological communities and habitats contribute to the designation of stable biogeographic regions across larger and deeper areas of the California Current.

Attempts to designate biogeographic deep-water zones are largely based on depth boundaries, and are quite large in area (Hartman and Barnard 1958, McClain and Hardy 2010, Watling et al. 2013). Depth is typically the primary environmental factor in determining megafaunal communities (Hardin et al. 1994, Levin et al. 2010, Love and Yoklavich 2006, Duffy et al. 2013). Infaunal (i.e., invertebrates living in soft sediments) assemblages become distinct at ~ 400-500 m relative to shallower water assemblages, with grain size and latitude also being important correlating environmental factors (Lissner et al. 1989, Hyland et al. 1994, Gillett et al. 2017, Henkel and Nelson 2018, Henkel and Gilbane 2020). The oxygen minimum zone (OMZ) shapes both assemblages in deeper waters off the US West Coast (Thompson et al. 1985, Levin et al. 1991, Levin 2003) and globally (Gooday et al. 2010, Stramma et al. 2010). While there are long-standing concepts about the presence of a provincial biogeographic boundary at Point Conception, which is situated to the south of the study area and marks the boundary between the northern Oregonian Province and the California Province to the south, we know of no such latitudinal province within the 135 km north or south of the study area.

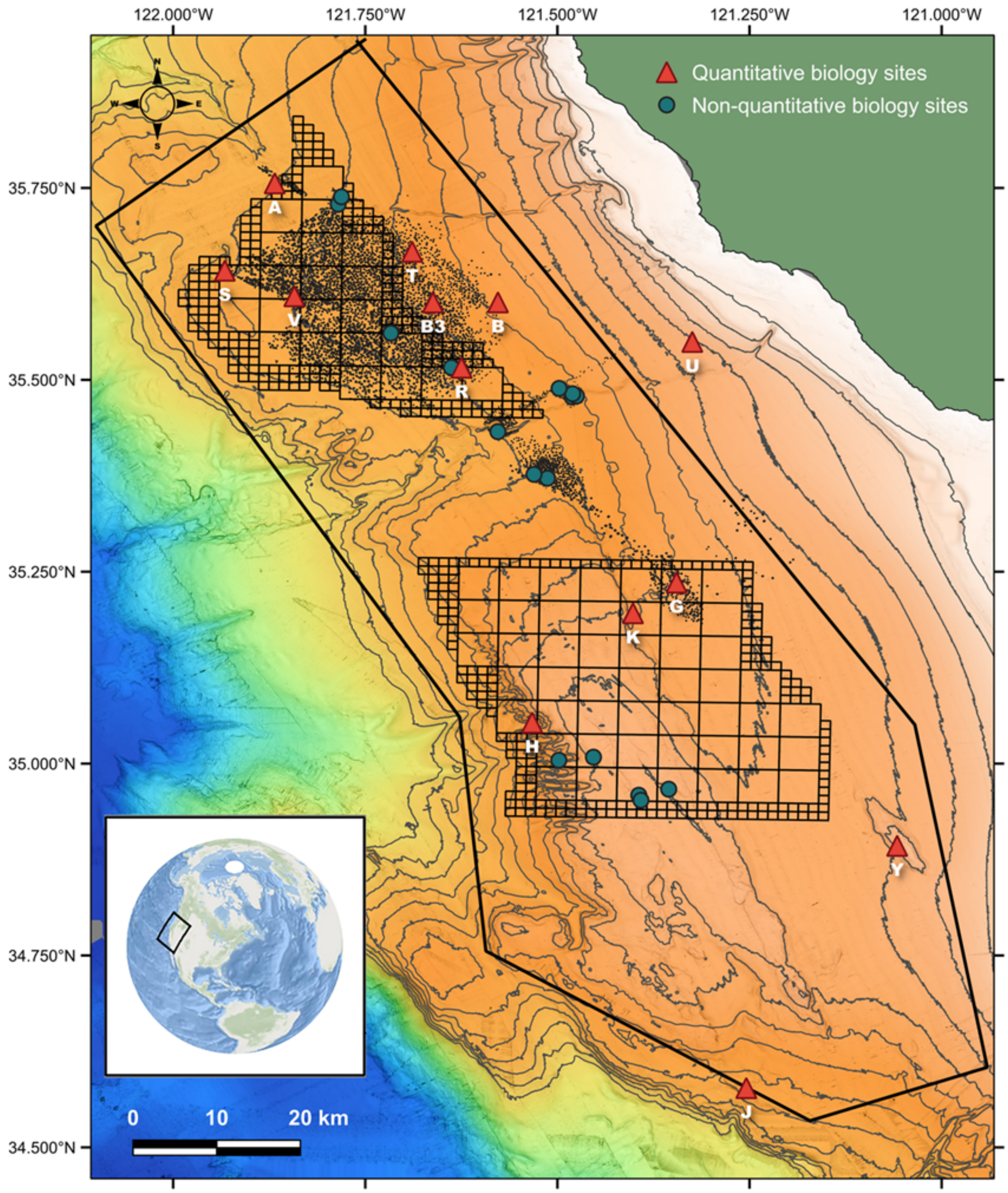

Figure 1. Region of study offshore of Morro Bay, central California from approximately 400 to 1200 m depth. The Cal DIG I study area is defined with a black polygon. Symbols show 13 lettered sites with red triangles, which indicate quantitative biological survey sites, and with green circles showing additional observation sites. Small fields of black dots illustrate the extent of pockmark fields (Lundsten et al. 2019). Two areas identified for potential future wind energy leases are overlain as a grid representing a partial lease blocks (BOEM 2018).

1.2 Goals and Objectives

The primary goal was to survey, document, and describe regional benthic megafaunal (fish and macroinvertebrate) community compositions employing a stratified sampling design to sample all depths and major habitat types based on existing Multibeam Echo Sounder (MBES) data. This study focused on the following three aspects of benthic species associations with surficial geology:

1. Do megafaunal density and biodiversity significantly differ between a water depth zone of 300-500 m, 501-700 m, 701-900 m, and > 900 m?
2. Do megafaunal density and biodiversity significantly differ between areas of soft substrate, pockmark field, and mixed/hard substrate?
3. Do localized biological communities (megafauna and infauna) inside individual pockmarks significantly differ from those outside the individual pockmarks?

This report is the first of three volumes to document and describe regional surficial and sub-bottom geological features and habitats to enable predictive modeling for unobserved portions of the region. This report describes the resulting remotely operated vehicle (ROV) observations and related physical data to groundtruth further habitat mapping efforts and map biotopes to the study area. Providing raw and derived data sets into Coastal and Marine Ecological Classification Standards (CMECS) of Water Column, Substrate, and Biotic components (Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee 2012).

We quantified the abundances of fish and macroinvertebrate species in association with varying depths, distinct surficial geologic environments, and physical environmental parameters (i.e., dissolved oxygen, temperature, salinity, slope, and rugosity [substratum roughness and increased surface area]). Because the pockmark depressions are unique features, we investigated potential differences in the macrofaunal and infaunal communities that live within them, as compared to the surrounding soft substrate habitat.

This report identifies biotopes, which incorporates the species composition and the physical setting in which megafauna live. Biotopes can be used to more accurately predict what is likely to be present in unobserved areas. The biological observations and environmental data captured in this project provide important information to characterize the seafloor and aid in the definition of marine ecosystems.

2 Methods

Multiple video surveys of the seafloor were combined from three separate cruises to the study area. A joint USGS-BOEM-MBARI cruise, which took place from 19–26 September 2019 on the R/V *Bold Horizon*, focused on conducting biological surveys using MBARI's *miniROV* (dives M137–148). Additional surveys were conducted from 02–14 February 2019 (dives D1120–1131) and from 01–11 November 2019 (dives D1202–1217) using MBARI's R/V *Western Flyer* and ROV *Doc Ricketts*.

2.1 Data Collection of Video and Physical Factors

Video was recorded with MBARI's *miniROV* using a Mini Zeus camera by Insight Pacific, fitted with a Sony FCB-H11 module and 5.1-51 mm 10 x zoom lens. *Doc Ricketts* ROV video was recorded with an Ikegama high-definition camera fitted with a HA10Xt.2 Fujinon lens. Both ROV's were equipped with two parallel laser beams, which were used to measure the width of the seafloor in the field of view. White balancing of the camera was done on each dive as the seafloor was approached. While transiting, ROV pilots sought to maintain the vehicle at a constant altitude off the seafloor (ranging from 1–4 m depending on the terrain. ROV altitude and speed over the bottom varied based on the terrain, water column currents, and ship handling conditions.

ROV positions were measured using Ultra short base line (USBL) systems with respect to a global positioning system (GPS) antenna on the ships. Instrumentation on the ROVs (situated 1-4 m above the seafloor) recorded pressure (i.e., depth; Valeport "Ultra P"), salinity (conductivity) and temperature (Valeport "Mini CT"). Dissolved oxygen from the ROV *Doc Ricketts* was taken at 1-4 m (Seabird SBE model 43), however the dissolved oxygen sensor on the *miniROV* was located on a clump weight traveled about 30 m above the seafloor during dives. Oxygen concentrations < 0.5 ml l^{-1} were considered to be in the OMZ (Levin 2003).

2.2 Video Annotation

To document and enumerate demersal and benthic megafauna, surficial geological habitats, biological detritus and anthropogenic debris from video, MBARI's Video Annotation and Reference System (VARS) was used at sea during cruises and onshore for post-cruise work (Schlining and Stout 2006). All areas observed during the cruises were characterized in "observational" mode (semi-quantitative) and quantitatively during linear seafloor transects at sites within the region (Figure 1). Taxonomic identifications of megafauna were made to the lowest practical taxonomic level for animals readily visible in video (~ 1 cm in size or larger). Video transects using an ROV may be less than effective for documenting highly mobile fishes. Most taxa annotated in this project are reflected in a dynamic web-based database called *The Deep-Sea Guide* (Jacobsen and Stout et al. 2020). Species and taxa identifications are presumptive, based on morphotypes, and the present-day knowledge of MBARI's benthic megafaunal experts. Taxa names were checked for validity against the World Register for Marine Species (WoRMS, http://www.marinespecies.org).

For all quantitative transects the ROV camera was adjusted to cover a 1 or 2 m-wide field of view. The width of the field of view was determined using the parallel laser beams in the video (14.5 cm apart for *miniROV,* 29 cm apart for *Doc Ricketts*). We measured the distance of travel using QGIS (v. 3.12.0-București) to establish an equal total area for each transect. Quantitative video transects were annotated by documenting each megafaunal animal. To avoid bias in counts of the number of megafauna due to field of view distortion due to the oblique camera view (Wakefield and Genin 1987), animals in the upper third of the image were not counted. Only those organisms passing through the midline swath of ROV video were used for counts.

2.3 Surficial Geologic Habitat Characterization

Surficial geologic habitats were documented using substratum, rugosity, and vertical slope designations (Table 1) by watching video and continuously annotating in observational mode. Each observation was first assessed for the primary habitat category based on substratum grainsize (following CMEC categorizations: mud, coarse sand, pebble, cobble, boulder, or bedrock) that constituted at least 50 % of the field of view (Table 1). A second substratum constituting at least an additional 20 % of the field of view was also noted. Mud and coarse sand were grouped into a soft substrate group. Cobble, boulder, and bedrock were grouped into a mixed/hard group. To more fully understand differences in biological communities, refine biotopes and to groundtruth MBES data, modifiers were employed (depression, dropstone, eroded [scouring], folded, hummocky [small regular mounds in the sediment], mud veneer, outcrop, and slabs).

General terms for rugosity of "flat" and "rugose" were used to comply with the CMECS data protocols. To enhance comparison of biological communities in multivariate analyses, primary habitat and rugosity were ranked in order of increasing rugosity and the highest surface area: mud, muddy coarse sand, hummocky mud, cobble, boulder, bedrock slab, and bedrock outcrop. Slope was visually estimated as a vertical angle of 0–5, 5–30, 30–60, or 60–90 degrees.

Table 1. Surficial habitat categories used for the documentation and analysis within the study area. Each of 7200 observations were assigned primary substratum*, secondary substratum, rugosity, and slope indicators. Modifiers were added to annotations to further define habitats and assist with mapping efforts. The top set of descriptors (frequently used) are referenced in other tables and figures in this report.

Primary Substratum (>50%)	Secondary Substratum (>20%)	Rugosity	Slope (degrees)	Modifiers
mud, coarse sand, pebble**, cobble, boulder, bedrock	mud, coarse sand, pebble**, cobble, boulder, bedrock	flat, rugose	0-5, 5-30 30-60, 60-90	*Frequently used:* folded, hummocky, mud veneer, outcrop, and slabs *Occasionally used*: depression, dropstone, and eroded

*Grainsize of substratum categories as defined by CMECs: mud = 90 % median < 0.0625, coarse sand = ≥ 90 % median 0.0625–0.125 mm, pebble = 4–62 mm, cobble = 64-255, boulder = 256–4096 mm bedrock = continuous formations of bedrock that cover 50 % or more.
**Not found in the study area and not used elsewhere in this report.

2.4 Megafaunal Communities

Megafaunal species were enumerated from video of the "observational" mode (semi-quantitative) and quantitatively during linear seafloor transects at sites within the region. Additional descriptions were made for fisheries, corals, anthropogenic, and biological debris.

Quantitative video transects were stratified by depth and substrate. The ROV sites were selected to identify species at four stratified depth classes; shallow (Zone 1, 300–500 m), mid-shallow (Zone 2, 500–700 m), mid-deep (Zone 3, 700–900 m), and deep (Zone 4, > 900 m; Table 2). High priority was given to collecting transects in soft substratum outside pockmark fields, soft substratum within pockmark fields, and hard or mixed substratum (mixed/hard) areas within each depth category based on MBES system data (Cochrane et al. 2021, in prep.). When possible, two to three widely distanced (> 7 km) locations were surveyed for site-level replication. Within a site, transects were replicated as many times as possible with a goal of three and a minimum distance of 1 km between transects. The targeted area for each transect was 200 m^2.

This design (Table 2) ensured adequate visual sampling to map habitats (Cochrane et al. 2021, in prep.) and define distinct benthic species groupings. Discrepancies between backscatter results and actual substrate yielded an incomplete replication of all stratified comparisons. At the shallow strata (Zone 1, 300-500 m) mixed/hard substrate was present only at Site Y in the south of study area, and no pockmark fields were present. At the mid-shallow (Zone 2, 500-700 m) pockmark fields were present only at Site G in the north of the study area. Weather issues prevented the collection of soft substrata from more than Site H.

2.5 Pockmark Field Biological Communities

To determine if unique biological communities exist within individual pockmarks compared with the non-pockmark areas outside them, we sampled sites within two geographically separated pockmark fields (Figure 1, Sites B3 and R).

Pockmark megafauna from video transects. We compared six quantitative transects at each of the two Sites, R (940 m depth) and B3 (870 m depth). Video used for this analysis was taken from six additional quantitative transects conducted at Site R and six repurposed transects conducted at Site B3. Twelve ROV transects were 200 m^2 each. We traversed a total of six individual pockmarks and an equal distance of the immediate non-pockmark surrounding area. Results from inside and outside three pockmarks at each of the two sites were combined for analysis since the transects were contiguous.

Pockmark infauna from sediment pushcores. Infaunal samples were collected using 6.9 cm diameter pushcores, which were inserted into the seafloor using the manipulator arm of ROV *Doc Ricketts*. Three pushcores were taken inside and three outside each of three individual pockmarks at Site R equaling 18 samples. Collections were replicated inside and outside of three pockmarks at Site G collecting another 18 samples for a total of 36 samples from both sites. Onboard, the top five cm of sediment was sieved, and infauna were preserved with 95 % EtOH. Organisms large enough to be retained on 300 μm sieve were sorted from sediments and identified by taxonomic experts through ABA Consultants, Santa Cruz, California.

2.6 Data Analysis

Relationships between the mean physical variables for each transect were tested against one another to determine their degree of correlation using Pearson Product Moment Correlation. Highly correlated variables ($r > 0.60$) were noted.

Since 86 % of the quantitative video transects (Table 2) covered 200 $m^{2,}$ data from annotated transects was used to construct species accumulation curves based on species richness. We evaluated each of the four depth and three substratum categories by reviewing species accumulation curves to see if the number of species reached an asymptote, which indicates sufficient sampling. From the quantitative video transects, counts of all animals and debris were totaled by transect and divided by the transect area to calculate the density of each taxa.

To examine biological community composition, species richness and density were calculated for each transect. Univariate analyses included a two-way analysis of variance (ANOVA) and Tukey-HSD post hoc tests to examine differences in the mean density and species richness within each depth and substratum category. Regional diversity was further examined by calculating the effective number of species (Hill number analysis), which includes the exponential of Shannon's entropy index and the inverse of Simpson's concentration index (Chao et al. 2009, 2014).

We conducted multivariate analysis to examine megafaunal communities using PRIMER-E v.7 non-metric multidimensional scaling (nMDS) based on a Bray Curtis similarity matrix (Clarke and Gorley 2015). Both square-root and 4th-root-transformed densities were tested in the model; the 4^{th}-root transform was conducted to minimize the effect of highly abundant mobile, and possibly transitory organisms such as ophiuroids (brittle stars). Hierarchical cluster analysis (group average) was performed to assess the validity of the depth and substratum groupings.

Next, we created "biotopes", which consist of biological communities that cluster together at 60% similarity or greater, without regard to pre-defined depth and substratum categories, and a description of the environmental conditions present for each grouping. To do this, we used the PRIMER-E v.7 similarity of profile routine (SIMPROF), which is a permutation procedure that tests for the presence of sample groups in *a priory* unstructured set of samples. SIMPROF groupings were determined by hierarchical cluster analysis (group average) for each individual transect to determine if there was a meaningful community structure and thus support for further exploration into correlations of the species with environmental variables (Clarke et al. 2008). We used the SIMPROF groupings where similarity was > 60 %, followed by a similarity profile global test for significance. To create an nMDS to depict our biotopes, we assigned a centroid position to represent the average position of all the transects within each SIMPROF group. We applied the mean values for environmental factors from all transects to explain the differences among the SIMPROF groups and define the biotopes. Segmented bubble plots overlaid each

SIMPROF groups and showed the relative weight of each environmental variable (Purcell et al. 2014). Similarity percentage analyses (SIMPER) calculated the individual species contributions within each biotope (e.g. SIMPROF groups).

To evaluate differences in density and species richness inside vs. outside pockmarks, paired, 2-tailed t-tests on video transects and infaunal samples were used.

Table 2. Stratified depth and substratum survey implementation for quantitative transects analyzed from sites within the California Deepwater Investigations and Groundtruthing I (Cal DIG I) defined study area. Video was collected from multiple (replicate) transects at 13 sites across four depth zones and three major substratum categories (soft, mixed/hard, and pockmark fields). Depth Zone 1 was 300-500m, Zone 2 was 500-700m, Zone 3 was 700-900m, and Zone 4 was 900-1000m. Note that no pockmark fields occur between 300–500 m depth and were limited at 500–700 m. The transects used in quantitative analysis are listed below with the transect identification code, starting latitude and longitude, minimum (Min) and maximum (Max) depth, and the transect width, length, and total area. * Transects also used in the inside/outside pockmark analysis, ** used exclusively in the inside/outside pockmark analysis.

Depth (m) Category	Substratum Category	Dive Number	Site-Transect Id Code	Transect Replicate	Starting Latitude/ Longitude	Depth Min (m)	Depth Max (m)	Width (m)	Length (m)	Area (m^2)
300–500	soft	M140	U-A	1	35.5495, -121.3245	410	413	2	100	200
300–500	soft	M140	U-B	2	35.5497, -121.3256	413	416	2	100	200
300–500	soft	M140	U-C	3	35.5497, -121.3271	417	420	2	100	200
300–500	soft	M140	U-D	4	35.5495, -121.3291	423	426	2	100	200
300–500	soft	M140	U-E	5	35.5495, -121.3302	426	427	2	100	200
300–500	soft	M140	U-F	6	35.5498, -121.3313	427	430	2	100	200
300–500	soft	M138	Y-2-A	7	34.9023, -121.0584	386	386	2	100	200
300–500	soft	M138	Y-2-B	8	34.9028, -121.0593	386	388	2	100	200
300–500	mixed/hard	M138	Y-1-A	1	34.8957, -121.0586	371	373	2	100	200
300–500	mixed/hard	M138	Y-1-B	2	34.8966, -121.0584	371	374	2	100	200
300–500	mixed/hard	M138	Y-1-C	3	34.8974, -121.0581	374	378	2	100	200
300–500	mixed/hard	M138	Y-3-A	4	34.9048, -121.0624	378	388	2	100	200
300–500	mixed/hard	M138	Y-3-B	5	34.9048, -121.0635	381	391	2	100	200
300–500	mixed/hard	M138	Y-3-C	6	34.9064, -121.0625	378	392	2	100	200
300–500	mixed/hard	M138	Y-4-A	7	34.9127, -121.0618	383	384	2	100	200
300–500	mixed/hard	M138	Y-4-B	8	34.9138, -121.0619	381	384	2	100	200
300–500	mixed/hard	M138	Y-4-C	9	34.9149, -121.0619	381	382	2	100	200
300–500	pockmark field	------	----------	----------		----------	----------	----------	----------	----------
501–700	soft	M139	H-4-A	1	35.0710, -121.5344	634	637	2	100	200
501–700	soft	M139	H-4-B	2	35.0721, -121.5345	627	633	2	100	200
501–700	soft	M139	H-4-C	3	35.0729, -121.5346	624	630	2	100	200
501–700	soft	M139	H-6-A	4	35.0804, -121.5393	672	686	2	100	200
501–700	soft	M139	H-6-B	5	35.0813, -121.5401	688	702	2	100	200
501–700	soft	M139	H-3-A	6	35.0641, -121.5349	696	703	2	100	200
501–700	soft	M139	H-3-B	7	35.0650, -121.5348	683	695	2	100	200
501–700	soft	M139	H-3-D	8	35.0819, -121.5407	700	714	2	100	200
501–700	mixed/hard	M139	H-5-A	1	35.0757, -121.5348	606	610	2	100	200
501–700	mixed/hard	M139	H-5-B	2	35.0768, -121.5357	608	611	2	100	200

Depth (m) Category	Substratum Category	Dive Number	Site-Transect Id Code	Transect Replicate	Starting Latitude/ Longitude	Depth Min (m)	Depth Max (m)	Width (m)	Length (m)	Area (m^2)
501–700	mixed/hard	M139	H-5-C	3	35.0776, -121.5362	611	619	2	100	200
501–700	mixed/hard	M140	H-1-A	4	35.0764, -121.5351	606	608	0.84	200	168
501–700	mixed/hard	D1212	K-E	5	35.2001, -121.4012	678	704	1	200	200
501–700	mixed/hard	D1211	K-F	6	35.2022, -121.4098	671	678	1	90	90
501–700	mixed/hard	D1211	H-3-C	7	35.0659, -121.5347	667	682	2	94	188
501–700	mixed/hard	D1211	K-G	8	35.2012, -121.4013	703	712	1	192	192
501–700	mixed/hard	D1211	K-H	9	35.2030, -121.4023	710	720	1	148	148
501–700	pockmark field	D1210	G-A	1	35.2370, -121.3469	691	695	1	200	200
501–700	pockmark field	D1210	G-B	2	35.2361, -121.3448	690	697	1	200	200
501–700	pockmark field	D1210	G-C	3	35.2370, -121.3463	691	692	1	200	200
701–900	soft	D1212	K-A	1	35.1963, -121.4026	719	728	1	200	200
701–900	soft	D1212	K-B	2	35.1969, -121.4046	726	729	1.75	114	200
701–900	soft	D1212	K-C	3	35.1975, -121.4049	729	731	1.75	92	160
701–900	soft	M142	B-1-A	4	35.6017, -121.5772	768	769	2	100	200
701–900	soft	M142	B-1-B	5	35.6017, -121.5787	770	771	2	100	200
701–900	soft	M142	B-1-C	6	35.6019, -121.5799	771	772	2	100	200
701–900	soft	M139	H-7-A	7	35.0838, -121.5428	745	759	2	100	200
701–900	soft	M139	H-7-B	8	35.0846, -121.5443	770	776	2	100	200
701–900	soft	M139	H-7-C	9	35.0857, -121.5447	779	796	2	100	200
701–900	mixed/hard	M139	H-2-A	1	35.0565, -121.534	775	796	2	100	200
701–900	mixed/hard	M139	H-2-B	2	35.0579, -121.5347	739	759	2	100	200
701–900	mixed/hard	M139	H-2-C	3	35.0588, -121.5349	720	737	2	100	200
701–900	mixed/hard	M139	H-8-A	4	35.0899, -121.5520	859	868	2	100	200
701–900	mixed/hard	M139	H-8-B	5	35.0905, -121.5530	859	863	2	100	200
701–900	mixed/hard	M139	H-8-C	6	35.0911, -121.5538	865	883	2	87	174
701–900	mixed/hard	D1212	K-D	7	35.1991, -121.4077	720	730	1	200	200
701–900	mixed/hard	M139	H-2-D	8	35.0572, -121.5347	771	758	2	100	200
701–900	mixed/hard	D1208	H-10-A	9	35.0415, -121.5549	860	898	1	200	200
701–900	pockmark field	M143	*B3-A	1	35.6014, -121.6622	868	868	2	100	200
701–900	pockmark field	M143	*B3-B	2	35.6021, -121.6633	868	871	2	100	200
701–900	pockmark field	M143	*B3-C	3	35.6026, -121.6643	871	874	2	100	200
701–900	pockmark field	M143	*B3-D	4	35.6043, -121.6656	869	869	2	100	200
701–900	pockmark field	M143	*B3-E	5	35.6056, -121.6663	871	876	2	100	200
701–900	pockmark field	M143	*B3-F	6	35.6091, -121.6678	868	873	2	100	200
701–900	pockmark field	M147	T-A	7	35.6671, -121.6892	870	873	2	100	200
701–900	pockmark field	M147	T-B	8	35.6679, -121.6899	872	875	2	100	200

Depth (m) Category	Substratum Category	Dive Number	Site-Transect Id Code	Transect Replicate	Starting Latitude/ Longitude	Depth Min (m)	Depth Max (m)	Width (m)	Length (m)	Area (m^2)
701–900	pockmark field	M147	T-C	9	35.6712, -121.6949	877	879	2	100	200
>900	soft	M137	J-1-A	1	34.5747, -121.2541	918	919	1	100	100
>900	soft	M137	J-1-B	2	34.5751, -121.2551	916	918	1	100	100
>900	soft	M137	J-1-C	3	34.5755, -121.2559	915	916	1	100	100
>900	soft	M145	S-A	4	35.6423, -121.9328	1172	1175	2	100	200
>900	soft	M145	S-B	5	35.6436, -121.9327	1173	1176	2	100	200
>900	soft	M145	S-C	6	35.6444, -121.9325	1165	1173	2	100	200
>900	soft	D1209	H-9-A	7	35.0785, -121.5775	1011	1041	1	200	200
>900	soft	D1209	H-9-B	8	35.0915, -121.5558	904	908	1	200	200
>900	soft	D1209	H-9-C	9	35.0923, -121.5579	903	1011	1	200	200
>900	mixed/hard	M137	J-2-A	1	34.5788, -121.2631	904	906	1	100	100
>900	mixed/hard	M137	J-2-B	2	34.5793, -121.2639	906	908	1	100	100
>900	mixed/hard	M137	J-2-C	3	34.5800, -121.2653	909	917	1	100	100
>900	mixed/hard	M145	S-D	4	35.6491, -121.9320	1118	1130	2	100	200
>900	mixed/hard	M145	S-E	5	35.6501, -121.9319	1105	1116	2	100	200
>900	mixed/hard	M145	S-F	6	35.6510, -121.9319	1103	1106	2	100	200
>900	mixed/hard	M145	S-G	7	35.6533, -121.9312	1100	1113	2	100	200
>900	mixed/hard	M145	S-H	8	35.6542, -121.9312	1114	1121	2	100	200
>900	mixed/hard	M145	S-I	9	35.6552, -121.9312	1109	1113	2	100	200
>900	pockmark field	M141	R-A	1	35.5159, -121.6248	936	938	2	100	200
>900	pockmark field	M141	R-B	2	35.5148, -121.6260	939	940	2	100	200
>900	pockmark field	M141	R-C	3	35.5141, -121.6262	940	943	2	100	200
>900	pockmark field	M141	**R-D	4	35.5135, -121.6261	940	940	2	100	200
>900	pockmark field	M141	**R-E	5	35.5143, -121.6280	940	940	2	100	200
>900	pockmark field	M141	**R-F	6	35.5155, -121.6294	940	940	2	100	200
>900	pockmark field	M141	**R-G	7	35.5170, -121.6305	940	940	2	100	200
>900	pockmark field	M141	**R-H	8	35.5184, -121.6315	940	940	2	100	200
>900	pockmark field	M141	**R-I	9	35.5193, -121.6333	940	940	2	100	200
>900	pockmark field	M144	A-A	4	35.7564, -121.8681	1111	1114	1.33	150	200
>900	pockmark field	M144	A-B	5	35.7578, -121.8698	1114	1118	1.33	150	200
>900	pockmark field	M144	A-C	6	35.7601, -121.8717	1120	1122	1.33	150	200
>900	pockmark field	M146	V-A	7	35.6093, -121.8423	1014	1014	2	100	200
>900	pockmark field	M146	V-B	8	35.6110, -121.8432	1014	1014	2	100	200
>900	pockmark field	M146	V-C	9	35.6125, -121.8448	1014	1014	2	100	200

3 Results

During the three cruises and 40 ROV dives we conducted, we traversed 46.8 km of the seafloor at an estimated average 4 m field of view. From 185 hours of observational and quantitative transects at 25 major sites, nearly 120,000 annotations were created (Figure 1). Results are given here for the four main components of investigation, culminating in the establishment of biotopes.

3.1 Physical Factors (Depth, Temperature, Salinity, Oxygen)

For benthic observations, depth ranged from 371–1176 m, oxygen from 0.25–0.81 ml l^{-1} (Figure 2), temperature from 3.6–7.0 ^{0}C (Figure 2), and salinity from 34.1–34.6 PSU. The results of the Pearson Correlation tests revealed that depth and salinity were positively correlated (r = 0.872, $p < 0.001$) depth and temperature were negatively correlated (r = -0.965, $p < 0.001$). Temperature and salinity were negatively correlated with each other (r = -0.799, $p < 0.001$). Oxygen was negatively correlated with depth (r = -0.575, $p < 0.001$). Data are consistent with a well-developed OMZ between 500–1150 m (Figure 2).

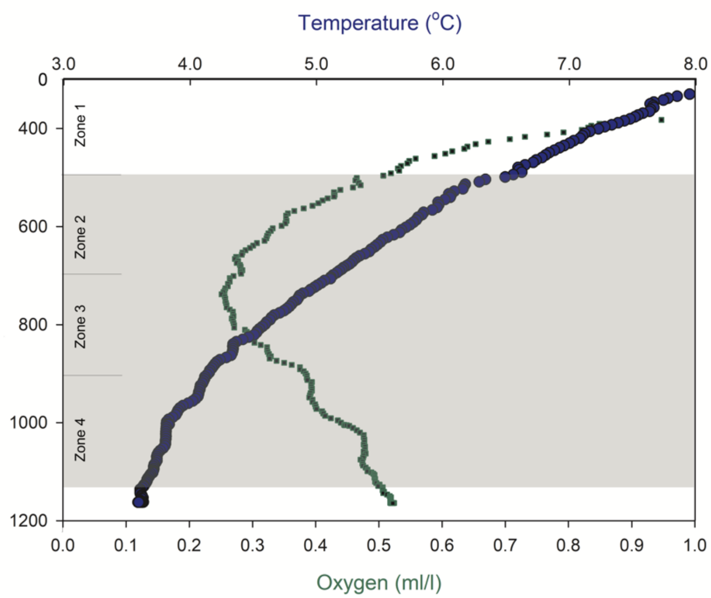

Figure 2. Oxygen (green symbols) and temperature (blue symbols) for a water column profile from the deepest dive conducted within the study region (M145). A well-formed oxygen minimum zone (grey) was evident between 500–1150 m water depth (y-axis) on this dive, with lowest oxygen levels at around 775 m. Zones 1-4 shown to the right of the y-axis indicate the depth categories used in the study design. Dive M145 was at site S in the northern part of the study area.

3.2 Surficial Geological Habitat Characterization

More than 7600 observations regarding the surficial geological habitat character were made. The primary substrate in areas surveyed was soft substrate (80 %, Figure 3 A–C, Table 3). Hummocky mud (Figure 3A, Table 3) occurred in 37.9 % percent of the region and was present at all depth zones, all oxygen levels and all temperatures. Greenish-black muddy coarse sand (Figure 3C) covered 17.5 % of the surveyed area. These sands occur on flat plains between hard bottom areas on Santa Lucia Bank. Trawl marks were evident on Santa Lucia Bank.

Areas estimated to be 100 % hard substrate (solid bedrock or outcrop, Figure 3F) were rare at 3.2 % of the surveyed area. In the analysis, hard substratum was combined with five other substrata categories that were a mix of hard and soft called 'mixed/hard' (totaled 19.8 % of the surveyed region, Table 3). The five mixed substrates included areas with varying amounts of cobble, eroded boulders, or broken slabs of bedrock combined with mud (Figure 3D, 3E). Bedrock slabs was the largest mixed/hard substratum representing 8.2 % of the areas surveyed. In some areas bedrock slabs in were ~ 2–5 cm thick, while others were > 30 cm thick. Pebble-sized rocks were only observed when they were brought to the seafloor surface in pushcores.

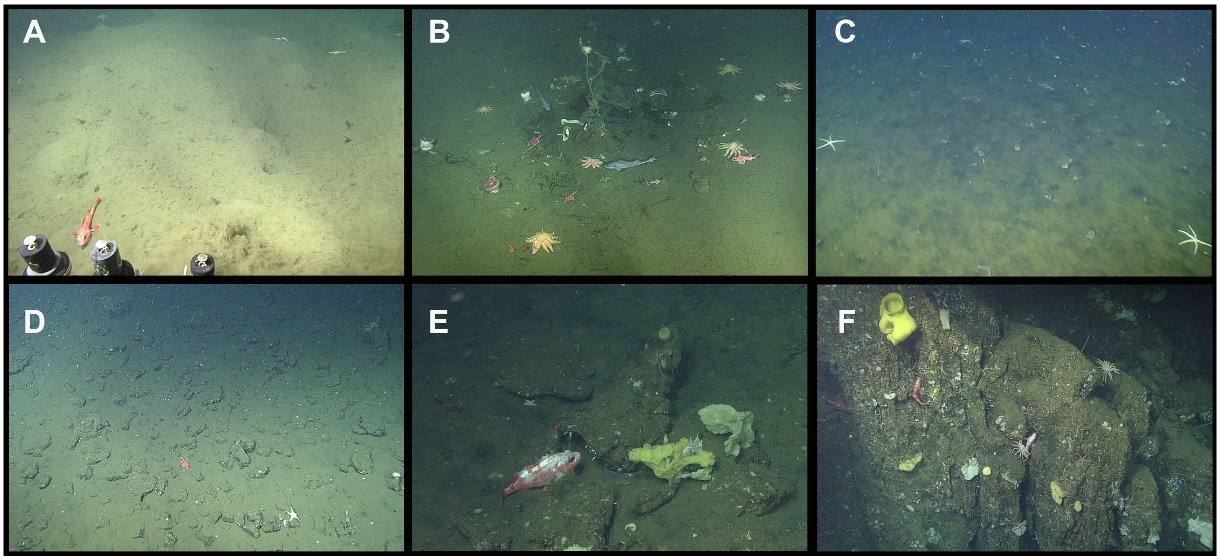

Figure 3. Geological habitats observed within the study region. A-C are soft substrates: A, hummocky mud (small, frequent mounds, 687 m depth); B, biological detritus, and marine litter (935 m); and C, mud with coarse greenish-black sand (766 m). D and E are a mix of soft and hard substrates: D, cobble (575 m) and E, bedrock slabs (477 m). F is the only type of hard substrate observed called bedrock outcrop (447 m).

The majority of the seabed within the study area was only mildly sloped and non-rugose (78 % 0–5 degree slopes, 71 % non-rugose, Table 4). Rugose (hard substrate-dominated) areas were generally on 5–30 + degree slopes and were observed in the southern portion of the region and at Site S in the north (Figure 1, Table 4). Very steep slopes (60–90 degrees) occurred at Sites K and S and were bedrock representing 3.2 % of the area surveyed.

Occasional patches of bacterial mat were observed, most under 15 cm in diameter, and presumably associated with decomposing organic material. A few larger mats were clearly covering decomposing kelp. We saw no evidence of the animal assemblages that are commonly associated with chemosynthetic biological communities (Sibuet and Olu 1998) near the observed bacterial mats or elsewhere on these dives and was supported by analysis of the water column data from two multibeam surveys in the area (Prouty and Baker 2020a, 2020b). All observations of bacterial mats occurred in the OMZ (Figure 2). Accumulations of dead sponge were present on slopes in the southern portion of the region, and at Site S to the north (Figure 4). The extent of these accumulations is not clear since the field of view with the ROV is limited to about a 4 m width. Dead *Farrea* and *Heterochone calyx* were most common. These may be important biogenic habitats that uniquely support a high diversity of other fauna that are too small to be observed with video.

Table 3. Summary of ROV dives conducted in the region and surficial geological habitat observations made (all transects, both quantitative and observational). Distance reflects the total linear path the ROV traveled during each dive. Benthic position at dive start is shown as latitude and longitude, as well as depth. Surficial geological habitat observations are placed into Soft or Mixed/Hard Substratum categories, each substratum category is further divided sub-categories with values indicating the estimated number of km present for that dive. Total distance (km) surveyed during all dives is summed at the bottom with the percentage of each habitat type.

Dive Number	Distance (km)	Starting Latitude	Starting Longitude	Starting Depth (m)	Mud	Mud Hum-mocky	Mud Coarse Sand	Mud Cobble	Mud Veneer	Total Soft Sub-strate	Cobble	Boulder	Bed-rock Folded	Bed-rock Slabs	Bed-rock Outcrop	Total Mixed/ Hard Sub-strate
D1120	0.6	35.515	-121.631	935.9	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
D1121	0.2	35.489	-121.499	833.4	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
D1122	0.9	35.378	-121.531	979.4	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
D1123	1.1	35.372	-121.512	955.4	1.1	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
D1124	0.7	35.433	-121.577	1057.6	0.1	0.6	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
D1125	0.5	35.391	-121.521	940.7	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
D1126	1.0	35.516	-121.638	951.6	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
D1127	0.8	35.475	-121.481	861.8	0.0	0.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
D1128	1.5	35.008	-121.500	816.9	0.1	0.0	0.3	0.0	0.0	0.4	1.1	0.0	0.0	0.0	0.0	1.1
D1129	0.7	34.964	-121.357	484.7	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.3
D1130	0.9	35.739	-121.781	993.2	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
D1131	0.7	35.647	-121.924	1126	0.7	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Cruise 1	**9.6**				**2.0**	**5.5**	**0.6**	**0.0**	**0.0**	**8.1**	**1.1**	**0.0**	**0.0**	**0.4**	**0.0**	**1.4**
M137	1.5	35.518	-121.632	935.7	0.9	0.4	0.0	0.0	0.0	1.4	0.2	0.0	0.0	0.0	0.0	0.2
M138	2.8	35.519	-121.632	932.6	0.2	0.0	0.0	0.0	0.9	1.1	0.6	0.0	0.0	0.8	0.3	1.7
M139	5.6	35.478	-121.481	820.1	1.5	0.2	3.6	0.0	0.0	5.3	0.3	0.0	0.0	0.0	0.0	0.3
M140	0.9	35.475	-121.471	843.8	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
M141	2.0	35.008	-121.456	483.4	0.0	2.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
M142	1.5	35.210	-121.407	750.1	0.0	1.5	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
M143	1.2	35.042	-121.560	983.2	1.2	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
M144	0.9	35.080	-121.580	1038.9	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
M145	2.1	35.236	-121.347	691.5	0.0	0.7	0.0	0.0	0.0	0.7	0.6	0.0	0.0	0.2	0.5	1.3
M146	0.6	35.198	-121.401	712.9	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
M147	0.9	35.196	-121.402	716.9	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
M148	0.8	34.952	-121.393	460.4	0.0	0.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Cruise 2	**20.9**				**3.9**	**9.0**	**3.6**	**0.0**	**0.9**	**17.4**	**1.7**	**0.0**	**0.0**	**0.9**	**0.8**	**3.5**
D1202	0.1	35.022	-121.396	435.8	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
D1203	0.6	35.188	-121.406	717.1	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0

Dive Number	Distance (km)	Starting Latitude	Starting Longitude	Starting Depth (m)	Mud	Mud Hum-mocky	Mud Coarse Sand	Mud Cobble	Mud Veneer	Total Soft Sub-strate	Cobble	Boulder	Bed-rock Folded	Bed-rock Slabs	Bed-rock Outcrop	Total Mixed/ Hard Sub-strate
D1204	0.4	35.563	-121.718	942.1	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
D1205	0.9	35.731	-121.786	986.3	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
D1206	1.2	34.574	-121.253	918.8	0.4	0.0	0.2	0.0	0.0	0.6	0.0	0.2	0.0	0.3	0.1	0.6
D1207	0.9	34.895	-121.059	377.7	0.0	0.0	0.6	0.0	0.3	0.9	0.0	0.0	0.0	0.0	0.0	<0.1
D1208	0.8	35.054	-121.533	893.7	0.0	0.0	0.0	0.0	0.3	0.3	0.5	0.0	0.0	0.0	0.0	0.5
D1209	1.1	35.549	-121.325	411.3	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	<0.1
D1210	1.1	35.516	-121.625	933.6	0.0	1.1	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
D1211	1.6	35.602	-121.577	768.5	0.6	0.0	0.7	0.0	0.0	1.3	0.0	0.0	0.0	0.3	0.0	0.3
D1212	1.3	35.601	-121.662	868	0.0	0.0	0.7	0.0	0.0	0.7	0.1	0.0	0.0	0.2	0.4	0.6
D1213	1.6	35.756	-121.868	1109.8	0.1	0.0	0.4	0.0	0.0	0.5	0.0	0.0	0.0	1.1	0.0	1.1
D1214	1.1	35.642	-121.933	1170.8	0.2	0.0	0.8	0.0	0.0	1.0	0.0	0.0	0.0	0.1	0.0	0.1
D1215	2.2	35.610	-121.842	1014.2	0.4	0.0	0.6	0.0	0.0	1.0	0.3	0.0	0.0	0.6	0.2	1.2
D1216	0.8	35.667	-121.689	870	0.8	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
D1217	0.6	35.745	-121.789	1004.3	0.6	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Cruise 3	**16.3**				**4.2**	**3.2**	**4.0**	**<0.1**	**0.6**	**12.0**	**0.9**	**0.2**	**<0.1**	**2.5**	**0.7**	**4.4**
Total (km)	**46.8**				**10.0**	**17.7**	**8.2**	**0.1**	**1.5**	**37.5**	**3.7**	**0.2**	**<0.1**	**3.8**	**1.5**	**9.3**
Percent of Total	**100.0**				**21.4**	**37.9**	**17.5**	**0.2**	**3.1**	**80.1**	**7.8**	**0.5**	**0.1**	**8.2**	**3.2**	**19.8**

Table 4. Summary of slope and rugosity observations for dives (all transects, both quantitative and observational video). Distance (km; also in Table 3) reflects the total linear path the ROV traveled during each dive. Values indicate the estimated distance (km) for each slope and rugosity category. Summed at the bottom are the total distance (km) and percent of all dives binned into each slope and rugosity category.

		Slope (Degrees)				Rugosity	
Dive Number	**Distance (km)**	**0-5**	**5-30**	**30-60**	**60-90**	**Flat**	**Rugose**
D1120	0.6	0.6	0.0	0.0	0.0	0.6	0.0
D1121	0.2	0.2	0.0	0.0	0.0	0.2	0.0
D1122	0.9	0.9	0.0	0.0	0.0	0.9	0.0
D1123	1.1	1.1	0.0	0.0	0.0	1.1	0.0
D1124	0.7	0.7	0.0	0.0	0.0	0.7	0.0
D1125	0.5	0.5	0.0	0.0	0.0	0.5	0.0
D1126	1.0	1.0	0.0	0.0	0.0	1.0	0.0
D1127	0.8	0.8	0.0	0.0	0.0	0.8	0.0
D1128	1.5	0.1	0.2	1.2	0.0	0.4	1.1
D1129	0.7	0.3	0.4	0.0	0.0	0.3	0.4
D1130	0.9	0.9	0.0	0.0	0.0	0.9	0.0
D1131	0.7	0.7	0.0	0.0	0.0	0.7	0.0
Cruise 1	**9.6**	**7.8**	**0.5**	**1.2**	**0.0**	**8.1**	**1.5**
M137	1.5	1.5	0.0	0.0	0.0	0.2	1.4
M138	2.8	1.7	1.1	0.0	0.0	0.9	1.9
M139	5.6	4.1	1.5	0.0	0.0	3.3	2.3
M140	0.9	0.9	0.0	0.0	0.0	0.9	0.0
M141	2.0	2.0	0.0	0.0	0.0	2.0	0.0
M142	1.5	1.5	0.0	0.0	0.0	1.5	0.0
M143	1.2	1.2	0.0	0.0	0.0	1.2	0.0
M144	0.9	0.9	0.0	0.0	0.0	0.9	0.0
M145	2.1	0.7	0.4	0.6	0.4	1.1	1.0
M146	0.6	0.6	0.0	0.0	0.0	0.6	0.0
M147	0.9	0.9	0.0	0.0	0.0	0.9	0.0
M148	0.8	0.8	0.0	0.0	0.0	0.8	0.0
Cruise 2	**20.9**	**17.0**	**2.9**	**0.6**	**0.4**	**14.4**	**6.5**
D1202	0.1	0.1	0.0	0.0	0.0	0.1	0.0
D1203	0.6	0.6	0.0	0.0	0.0	0.6	0.0
D1204	0.4	0.4	0.0	0.0	0.0	0.4	0.0
D1205	0.9	0.9	0.0	0.0	0.0	0.9	0.0
D1206	1.2	0.2	0.8	0.2	0.0	0.2	1.0
D1207	0.9	0.6	0.2	0.1	0.0	0.5	0.4
D1208	0.8	0.3	0.5	0.0	0.0	0.3	0.5
D1209	1.1	1.1	0.0	0.0	0.0	1.1	0.0
D1210	1.1	1.1	0.0	0.0	0.0	1.1	0.0
D1211	1.6	0.8	0.7	0.0	0.0	1.0	0.5
D1212	1.3	0.7	0.1	0.5	0.0	0.7	0.6
D1213	1.6	1.6	0.0	0.0	0.0	0.5	1.1
D1214	1.1	1.0	0.1	0.0	0.0	1.0	0.1
D1215	2.2	0.6	0.7	0.8	0.1	0.6	1.5
D1216	0.8	0.8	0.0	0.0	0.0	0.8	0.0
D1217	0.6	0.6	0.0	0.0	0.0	0.6	0.0
Cruise 3	**16.3**	**11.7**	**3.0**	**1.6**	**0.1**	**10.5**	**5.8**
Total (km)	**46.8**	**36.5**	**6.4**	**3.4**	**0.5**	**33.0**	**13.8**
Percent of Total	**100.0**	**77.9**	**13.7**	**7.3**	**1.0**	**70.5**	**29.5**

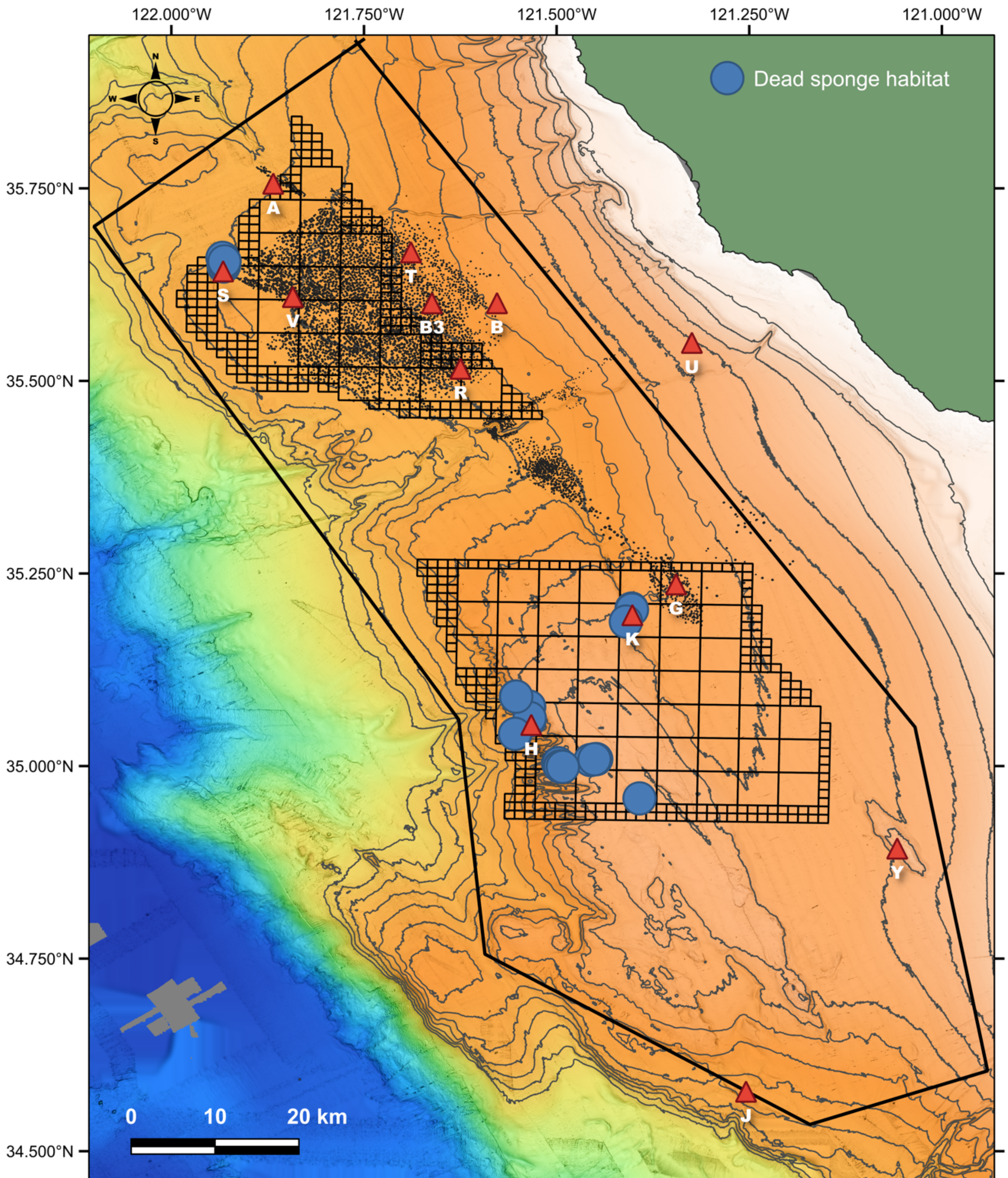

Figure 4. Map of general areas where dead sponge skeletons were observed. Dead skeletons may provide unique habitat for dense numbers of organisms too small to be seen on video.

3.3 Megafaunal Community Summary: Observational and Quantitative Video

Over 101,000 megafaunal organisms from among at least 220 presumptive taxa were observed in observational and quantitative video (Appendix A). Echinoderms (sea cucumbers, sea stars, brittle stars, urchins, and crinoids) were the most abundant phylum-level group and comprised 46 different taxa (Figure 5). Vertebrate chordates (bony fishes and elasmobranchs) were also abundant and represented the most speciose group (54 taxa). The most abundant benthic organisms were mobile (71.8 %: sessile = 28.2 %, Appendix A). Sessile animals were associated with hard substratum, but present in high numbers in muddy areas as well in the form of sea pens and anemones. Evaluation of trophic levels for megafauna revealed 35 % predator/scavengers, 34 % surface deposit feeders, and 30 % suspension/filter feeders. Few subsurface deposit feeders and mixed-feeding animals were observed.

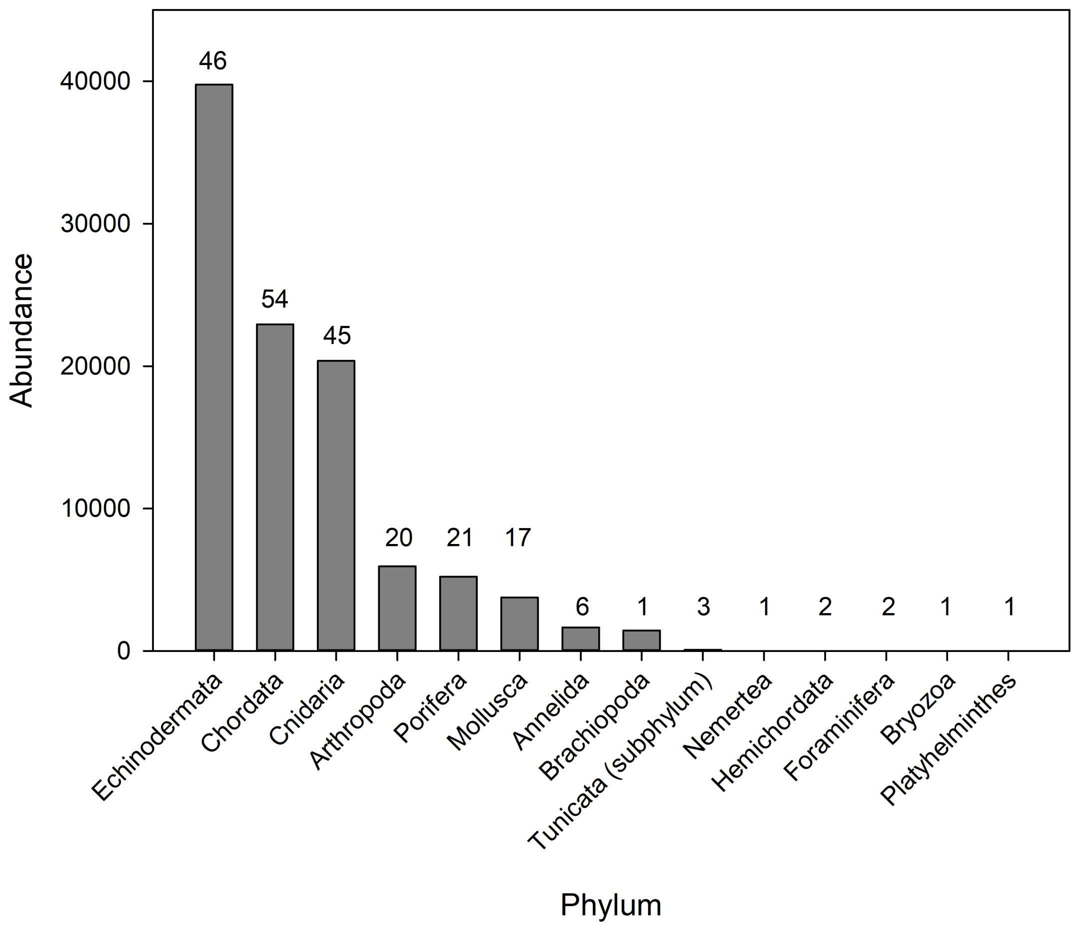

Figure 5. The abundance of megafaunal observations from quantitative and observational dives by phylum. The number of taxa represented by each group is listed above each bar.

Cnidarians (anemones, corals, and sea pens) were consistently observed in the region, and represented by 45 taxa. Small paragorgids (likely *Paragorgia stephencairnsi* or *P. yutlinux* (n = 119) and *Swiftia* spp. (n = 729) were present on rocky slopes. *Alternapathes* (n = 13) and *Parastenella* (n = 11) were sparse. *Isidella tentaculum* were rare and relatively small in size when encountered (n = 5).

Nearly 5000 dead and dying pyrosome tunicates were observed on the seafloor (Figure 6). Other pelagic debris present in some of the same areas included dead salps. A layer of phytodetritus accumulation on the seafloor was apparent at the most southerly location we visited (Site J, Figure 1). Shallow-water plant material accumulated in areas consisting of kelp fronds, holdfasts and eel grass. The empty shells (tests) of burrowing irregular urchins (Spatangoida) were seen in areas with hummocky mud between the depths of 412–1005 m.

3.4 Anthropogenic Debris

A total of 255 items of marine litter were observed throughout the 46.8 km of seafloor observed (Figure 7). Items were dispersed across the entire depth range. Concentrated accumulations (numerous items per area) occurred in pockmark fields, where there was rugose rocky terrain, and near channels (Figure 7). Plastic and unidentifiable trash were most abundant. Items included metal, plastic, ceramic and glass drinking containers, paint buckets, fabric, a shoe, fishing nets, fish traps, rope, and a ship wreck (https://sketchfab.com/models/e8cd4cfbfe5e44c79ccd7a7b1f01d86d).

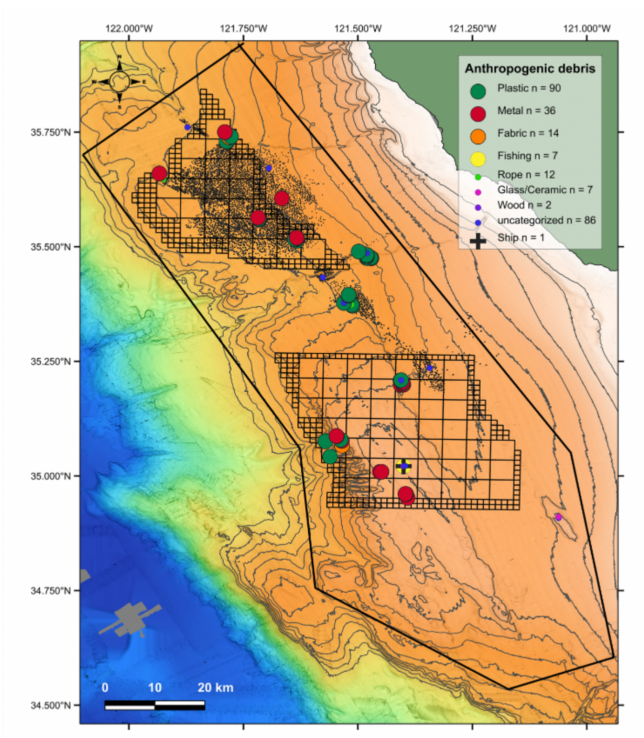

Figure 6. Map showing where accumulations of anthropogenic debris were observed. Symbol size is for visibility in layers and is not indicative of trash abundance.

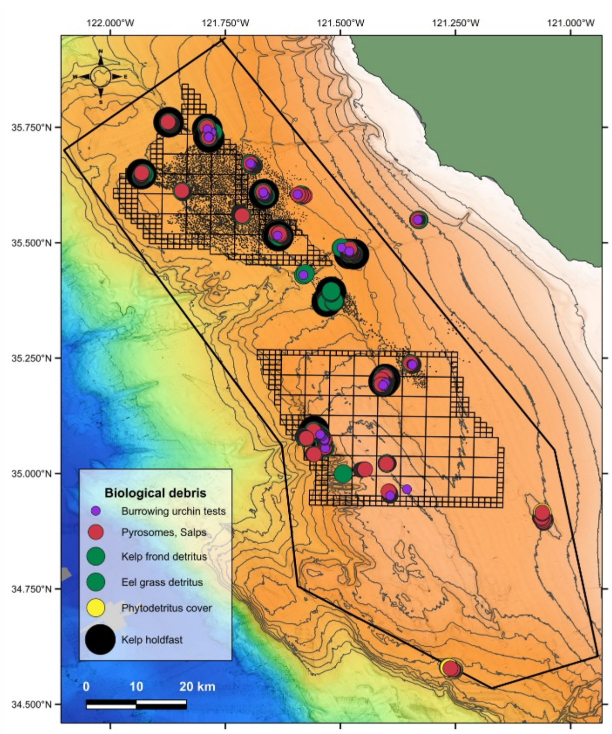

Figure 7. Map showing where accumulations of biological debris were observed. Symbol size is for visibility in layers and is not indicative of debris abundance.

3.5 Fisheries

A portion of the study area overlaps Essential Fish Habitat (EFH) and Habitat Area of Particular Concern (HAPC) as defined by NOAA Fisheries (Figure 8, See also NOAA 2020). No endangered or threatened fishes in the Endangered Species Act were observed during this investigation (Appendix A). All sites are outside the California Department of Fish and Wildlife (CDFW) Cowcod Conservation area.

Some groundfish observed during the study are monitored as sustainable fisheries by NOAA (Table 5). Thornyheads (*Sebastolobus* spp.) were the most abundant taxa amongst this group. All monitored species were observed both inside and outside the EFH and HAPC. Other relevantly abundant species present in the EFH and HAPC areas included *Eptatretus* (hagfish), *Lycenchelys crotalinus* (snakehead eelpout), *Lycodapus fierasfer* (blackmouth eelpout), and *Sebastes melanostomus* (blackgill rockfish).

Table 5. Observed sustainable fish species monitored by NOAA Fisheries. Number of individuals of five selected fish species observed in all quantitative transects. Area refers to approximate locations with biological sites of the study area (see Figure 9). The last column is the number of individuals observed in Essential Fish Habitat (EHF) and Habitat Areas of Particular Concern (HAPC) portions of the study area.

Common Name	Species Name	Number Observed	Area	Number Observed within EHF/HAPC
Dover sole	*Microstomus pacificus*	1168	Throughout	557
Pacific whiting	*Merluccius productus*	87	Throughout	65
Rex sole	*Glyptocephalus zachirus*	316	Sites U, H, K, Y	153
Sablefish	*Anoplopoma fimbria*	638	Throughout	282
Thornyhead	**Sebastolobus alascanus*	14711	Throughout	4789

* Cannot always be distinguished from *S. altivelis* from video, therefore both species are included here.

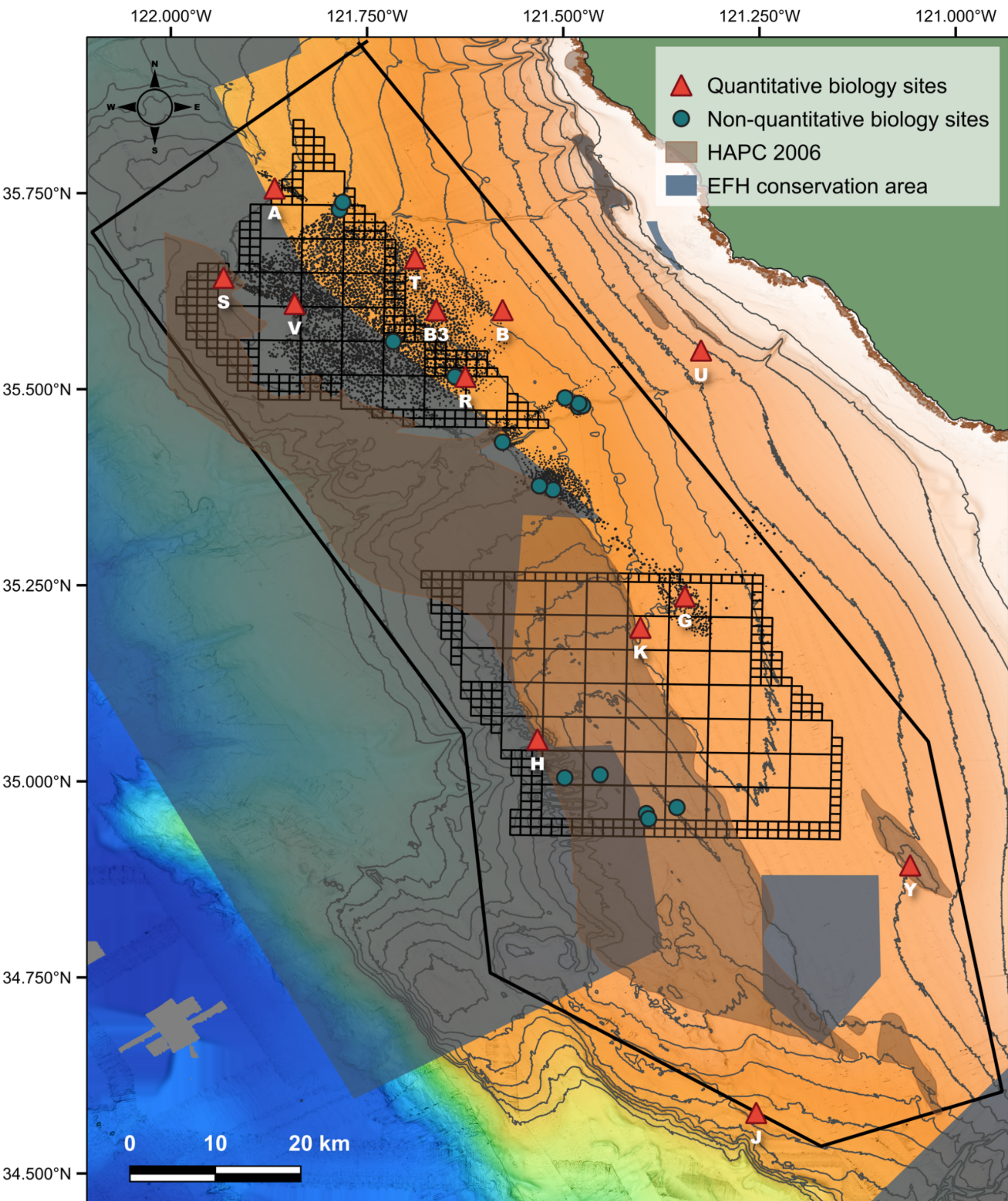

Figure 8. NOAA Fisheries Essential Fish Habitat (EFH) areas as of 2019, and Habitat Areas of Particular Concern (HAPC) zones as of 2006 within the study area.

3.6 Megafaunal Community Associations with Depth and Substrate: Quantitative Transects

We conducted 91 quantitative transects at 13 major sites over 185.2 km^2 (Figure 1, Table 2). The *Doc Ricketts* ROV surveyed 16 transects at three sites and the *miniROV* surveyed 81 transects at 10 sites over 11 dives. There were 173 taxa observed on transects (Appendix A). Overall species richness on individual transects ranged from 8–55 taxa and densities from 0.11–12.9 m^{-2}.

Replication of transects at multiple region-wide sites was not always possible for each of the four depth zones and three substrate zones analyzed (Table 2), resulting in pseudo-replication for some analyses. This may have limited detection of variation in species and abundances at the depth zone 300–500 m with mixed/hard substrate and the 500–700 m soft substrate and pockmark field transects. This effect was mitigated by separating each transect at the same general site by 1–5 km. Species accumulation curves demonstrate that for most depth vs. substratum categories, species richness was nearing an asymptote, indicating sufficient sampling (Appendix B). A notable exception was from 500–700 m depth in pockmarks fields where we were only able to conduct three transects. Ninety-one transects were used for site-specific community analysis.

3.6.1 Univariate Analyses

Depth. The mean density of organisms observed within our four defined depth ranges varied from 1.0–3.6 m^{-2}, declining significantly with depth (Table 6). ANOVA results were significant for density amongst depth categories ($F(3,91) = 6.6$, $p < 0.001$, Table 6). A Tukey-HSD post-hoc test revealed significant pairwise differences in the mean density of organisms between 300-500 m vs. > 900 m ($p = 0.003$), and 500-700 vs. > 900 m ($p < 0.001$, Table 6). There was no significant difference in species richness for depth categories ($F(3,91) = 1.5$, $p = 0.23$, range = 21–27 taxa). Additional diversity indices (Hill numbers) exponential of Shannon's entropy index and Shannon's Diversity are shown in Table 5 and show a similar pattern.

Substratum. The density of megafauna was significantly different amongst our substratum groups ($F(3,91) = 8.9$, $p < 0.001$, Table 6). Highest species richness was observed in mixed/hard substratum habitats (3.7 m^{-2} ± SD 2.9) and was lowest in soft substratum and pockmark fields (indistinguishable at 1.6 m^{-2} each ± 1.8, SD 1.9). The Tukey-HSD post-hoc test revealed significant pairwise differences between mixed vs. pockmark ($p = 0.004$) and mixed vs. soft substrates ($p = 0.001$, Table 7).

Species richness showed the same pattern as density and was significantly different by substratum. Mixed/hard substratum was highest at 34.3 ± SD 7.7. Comparable means were observed for soft substratum (16.4 m^{-2} ± SD 5.6) and pockmark fields (15.6 m^{-2} ± SD 4.6) ($F(3,91) = 88.6$, $p < 0.001$). The Tukey-HSD post-hoc test revealed significant pairwise differences between mixed vs. pockmark ($p < 0.001$) and mixed vs. soft substrates ($p < 0.001$). Additional diversity indices (Hill numbers) exponential of Shannon's entropy index and Shannon's Diversity are shown in Table 6.

Depth vs. Substratum. Both density and species richness were significant for depth vs. substratum categories (both $p < 0.001$, Table 6). Results of Tukey-HSD post-hoc tests shows statistically significant differences for numerous categories (Table 7).

Table 6. Mean megafaunal diversity and density (± = standard deviation) results by depth and substratum for 91 quantitative transects. (Top) Values in **bold** are totals for the number of transects (n), species richness (S), exponential of Shannon's entropy index (expH'), inverse of Simpson's index (1/γ) and transect density (m^{-2}). Categories are ordered from four depth zones (shallow to deep) and below that the totals of each substratum (soft, mixed/hard, and pockmark field). **(Bottom)** Results of 2-Way ANOVA tests (α = 0.05) show that density was significantly different for depth and substratum. Species richness was significant for substratum, but not for depth. Both density and species richness were sig. for the interaction depth x substrate.

Transect Type	n	S	expH'	1/γ	Density (m^{-2})
300–500 m	**17**	**21.5 ± 9.8**	**4.3 ± 2.6**	**1.0 ± 1**	**3.6 ± 2.2**
mixed/hard	9	28.8 ± 5.6	6.4 ± 1.8	1.0 ± 0.1	5.1 ± 1.5
soft	8	13.3 ± 6.5	2.0 ± 0.56	1.2 ± 1.7	1.8 ± 1.2
501–700 m	**20**	**27.1 ± 8.8**	**8.6 ± 3.8**	**1.6 ± 1.4**	**3.5 ± 3.4**
mixed/hard	9	34.2 ± 7.5	10.8 ± 4.3	1.3 ± 0.7	4.1 ± 3.3
pockmark field	3	24.3 ± 4.2	6.0 ± 0.6	1.0 ± 0.2	5.2 ± 2.6
soft	8	20.1 ± 3.8	7.1 ± 2.5	2.3 ± 2.3	2.4 ± 3.6
701–900 m	**27**	**24.1 ± 13.3**	**8.6 ± 5.0**	**5.5 ± 9.9**	**2.3 ± 2.6**
mixed/hard	9	40.8 ± 8.1	14.3 ± 4.2	1.1 ± 0.2	4.5 ± 3.8
pockmark field	9	14.8 ± 2.8	5.3 ± 1.1	6.7 ± 8.7	1.3 ± 0.3
soft	9	16.7 ± 5.6	6.1 ± 1.9	9.2 ± 15.3	1.2 ± 0.5
>900 m	**27**	**20.9 ± 10**	**8.8 ± 5.1**	**11.8 ± 23.0**	**1.0 ± 0.4**
mixed/hard	9	33.3 ± 5.1	15.0 ± 2.2	17.5 ± 31.8	1.1 ± 0.2
pockmark field	9	13.6 ± 2.7	5.6 ± 1.5	11.2 ± 13.2	0.7 ± 0.4
soft	9	15.7 ± 5	5.9 ± 3.6	4.2 ± 5.4	1.0 ± 0.4
Mixed/hard	**36**	**34.3 ± 7.7**	**4.8 ± 15.8**	**11.6 ± 4.7**	**3.7 ± 2.9**
Pockmark field	**21**	**15.6 ± 4.6**	**6.0 ± 8.3**	**5.5 ± 1.2**	**1.6 ± 1.8**
Soft	**34**	**16.4 ± 5.6**	**4.5 ± 8.7**	**5.3 ± 3.0**	**1.6 ± 1.9**

		2-Way ANOVA			
Factor	**SS**	**df**	**MS**	**F**	***p***
Density (m^{-2})					
Depth	110	3	36.6	6.6	<0.001
Substratum	99.2	2	49.6	8.9	<0.001
Depth x substratum	243.1	10	24.3	5.6	<0.001
Error	348.1	80	4.3		
Species Richness (m^{-2})					
Depth	520	3	173	1.5	0.227
Substratum	7176	2	3588	88.6	<0.001
Depth x substratum	8299	10	829	27.2	<0.001
Error	2439	80	30.4		

Table 7. Results of Tukey-HSD post hoc tests for density and species richness. Levels for the given parameters and factors that were significantly different *(p)* in Table 6. Factor d x s = depth x substrate.

Parameter	Factor	Level	Level	*p*
Density	depth	300–500	>900	<0.001
	depth	500–700	>900	<0.001
	substratum	mixed/hard	pockmark field	0.003
	substratum	mixed/hard	soft	0.001
	d x s	mixed/hard 300–500	mixed/hard >900	0.005
	d x s	mixed/hard 300–500	pockmark field 700–900	0.008
	d x s	mixed/hard 300–500	pockmark field >900	0.001
	d x s	mixed/hard 300–500	soft 700–900	0.006
	d x s	mixed/hard 300–500	soft >900	0.004
	d x s	mixed/hard 500–700	pockmark field >900	0.030
	d x s	mixed/hard 700–900	mixed/hard >900	0.036
	d x s	mixed/hard 700–900	pockmark field >900	0.010
	d x s	mixed/hard 700–900	soft 700–900	0.042
	d x s	mixed/hard 700–900	soft >900	0.026
Species Richness	substratum	mixed/hard	pockmark field	<0.001
	substratum	mixed/hard	soft	<0.001
	d x s	mixed/hard 300–500	mixed/hard 700–900	0.001
	d x s	mixed/hard 300–500	pockmark field 700–900	<0.001
	d x s	mixed/hard 300–500	pockmark field >900	<0.001
	d x s	mixed/hard 300–500	soft 300–500	<0.001
	d x s	mixed/hard 300–500	soft 700–900	0.001
	d x s	mixed/hard 300–500	soft >900	<0.001
	d x s	mixed/hard 500–700	pockmark field 700–900	<0.001
	d x s	mixed/hard 500–700	pockmark field >900	<0.001
	d x s	mixed/hard 500–700	soft 300–500	<0.001
	d x s	mixed/hard 500–700	soft 500–700	<0.001
	d x s	mixed/hard 500–700	soft 700–900	<0.001
	d x s	mixed/hard 500–700	soft >900	<0.001
	d x s	mixed/hard 700–900	pockmark field 500–700	0.001
	d x s	mixed/hard 700–900	pockmark field 700–900	<0.001
	d x s	mixed/hard 700–900	pockmark field >900	<0.001
	d x s	mixed/hard 700–900	soft 300–500	<0.001
	d x s	mixed/hard 700–900	soft 500–700	<0.001
	d x s	mixed/hard 700–900	soft 700–900	<0.001
	d x s	mixed/hard 700–900	soft >900	<0.001
	d x s	mixed/hard > 900	pockmark field 700–900	<0.001
	d x s	mixed/hard > 900	pockmark field >900	<0.001
	d x s	mixed/hard > 900	soft 300–500	<0.001
	d x s	mixed/hard > 900	soft 500–700	<0.001
	d x s	mixed/hard > 900	soft 700–900	<0.001
	d x s	mixed/hard > 900	soft >900	<0.001

3.6.2 Multivariate Analyses

The similarity of biological communities can be visualized and further analyzed by using ordination methods. Square-root and fourth-root transformed data were very similar, with only minor differences in Bray Curtis similarity matrix (based on species and diversity) for transects. The 4th-root transform produced an nMDS plot with less stress (goodness of fit; 0.16 vs. 0.17 for square-root transformed data). Both stress levels indicate a good representation of these data. A plot showing the nMDS data (Figure 9) illustrates the relationships of individual transects (shown as a symbol) for the four depth categories and three substratum types. The relative similarity of the species composition and abundances observed on each transect form identifiable groups. The closer the transects on the group plots are located, the more similar the biological communities.

Overall, based on the cluster analysis, transects within the depth vs. substratum categories were less than 40% similar; the ellipses reveal numerous non-depth and substratum related clusters, even at this low similarity percentage (Figure 9). Depth ranges are only generally clustered together. Mixed/hard substratum transects generally cluster together, supporting the finding from univariate analyses (Section 3.6.1) that densities and species richness for mixed/hard substratum was significantly different from them both. There is some, but not complete, clustering of soft and pockmark field substratum transects. While the mean densities and species richness for soft and pockmark field were not significantly different (Section 3.6.1), nMDS analysis does shows a community separation.

Total count of species and the individual species found in the depth and substratum categories were different (500–700 m, 52 total species, 55.8 % overlap between soft and pockmark field megafauna; 700–900 m, 49 species with 61.2 % overlap; > 900 m, 49 species, 53.1 % overlap).

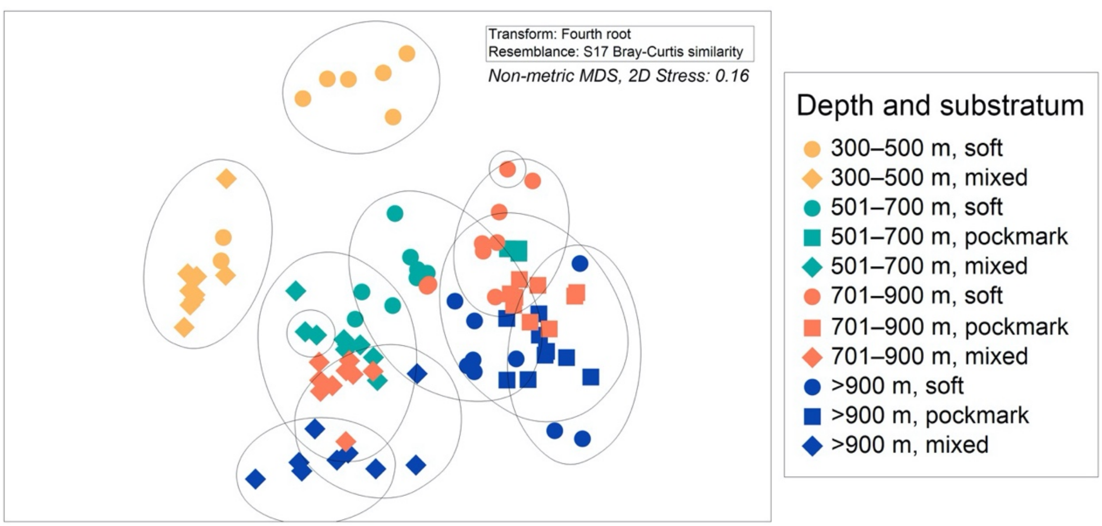

Figure 9. Non-metric multidimensional scaling (nMDS) ordination of megafaunal densities highlighting depth and substratum categories. Based on a Bray-Curtis species density similarity matrix on 4th-root transformed data. Individual transects are plotted as symbols. The closer in space symbols are located, the more similar the biological community, based on the species and densities present within the transects. Ellipses indicate biological communities formed by individual transects at the 40 % similarity level (based on cluster analysis) and ellipses reveal numerous non-depth and substratum related clusters. Overall, depth and substratum categories generally cluster together and support the univariate findings of significant differences with depth and substrate.

3.6.3 Biotopes

The original depth and substratum categories describe the study area in sufficient detail to show general trends, but there is not enough of a signal to fully define the habitats present. The a priori depth and substratum groups clustered at < 40 % indicating low similarity in the broad design, therefore we moved beyond our initial hypothesis and further analysis was undertaken in an effort to explain additional environmental conditions that better define communities and biotopes.

Our SIMPROF analysis was conducted to cluster sites > 60 % similarity without regard to a priori group structure. In this analysis, depth and substratum categories are ignored and biological community structure alone formed groupings. The SIMPROF null hypothesis of an absence of structure was rejected (sample statistic = 0.1, $\pi = 7.23$), and eighteen SIMPROF groups were formed where three or more transects combined in similarity (Table 8, Appendix C). These groups reflect 77 % of megafaunal transects in the analysis (Figure 10). We used these groups to define biotopes by describing the environmental conditions that were present when highly similar megafaunal assemblages occurred. SIMPER analysis provided the contribution of each species to biotope groupings (Table 8, Appendix C).

Oxygen Minimum Zone (OMZ). Sixty-eight percent of individual transects (n = 62 of 91) and 72 % of biotopes (n = 13 of 18) were located within the OMZ. We presumed transects with no measurements were in the OMZ because their depths were fully within the low oxygen zone (Figure 2). Biotopes 2, 3, 4, 5, 6, 10, 11, 12, 13, 15, 16, 17 and 18 (Figure 2, Table 8) were all located in low oxygen conditions where we observed 117 taxa. Mean diversity at low oxygen levels was variable and ranged from 15.7–45.7 taxa (Table 8). Highest diversities within the OMZ were observed on 5–30 degree slopes with bedrock and bedrock slabs, and lowest in mud-laden areas. Mean densities were also variable and ranged from 0.6–6.7 m^{-2}. Highest density within the OMZ occurred on 5–30 degree slopes with bedrock and bedrock slabs, and at the highest temperatures. Low densities occurred in mud and muddy coarse sand habitats.

The most dissimilar biotopes were 1, 7, 8, 14 and 16 (Figure 10) and are described here. See Table 8 and Appendix C for further summary and details of all 18 biotopes.

Biotope 1. Communities were 61 % similar to each other and found on hummocky soft mud on flat terrain at Site U (Figure 1). This community was located at shallow depths ($\bar{x}$ = 421 m ± SD 6.8), and at relatively high oxygen concentration and temperatures. This biotope exhibits a low mean number of taxa (10.5 ± SD 1.7) and relatively low megafaunal abundance (1.1 m^{-2} ± SD 0.8). The community was heavily dominated by the sea star *Myxoderma platyacanthum*, a mobile surface deposit feeder and secondarily by the flatfish *Microstomus pacificus*.

Biotope 7. Communities were 80 % similar to each other. Substratum consisted of cobble-sized rock on a 5–30 degree slope. This highly rugose, high-surface area habitat (Site Y, Figure 1) at shallow depth ($\bar{x}$ = 379 m ± SD 4.8) with relatively high oxygen levels and temperatures supported a large number of taxa ($\bar{x}$ = 33 ± SD 1.8) and a high mean abundance of 5.0 m^{-2} ± SD 0.2. Ophiacanthid brittle stars were in high abundance at these sites as was the urchin *Strongylocentrotus fragilis*. Seventy-five percent of organisms were mobile and 69 % were surface deposit feeders.

Biotope 8. Exhibited 69 % community similarity. The surficial habitat consisted of mud with 10 % bedrock slab on 30–60 degree slopes. All transects were at Site S (Figure 1) at a mean of 1111 m depth (± SD 6.0). Oxygen levels were just above the level used to define the OMZ, and temperatures were low. This area supported high diversity ($\bar{x}$ = 35 taxa ± SD 6.6; crustaceans, brittle stars, sponges, sea stars, sea cucumbers, etc.), but low density ($\bar{x}$ = 1.1 m^{-2} ± SD 0.03). The community was comprised mostly of mobile predators/scavengers, mobile surface deposit feeders, along with sessile suspension/filter feeders.

Biotope 14. Exhibited 63 % community similarity. These transects were located on flat muddy bottom with no bedrock slab, also at Site S. Located at slightly deeper depth, ($\bar{x}$ = 1173 m ± SD 2.6), they were also exhibited relatively high oxygen concentrations and low temperatures. Low abundance and low diversity ($\bar{x}$ = 10.7 taxa ± SD 2.1, 0.5 m^{-2} ± SD 0.02) was observed. The functionally mobile "tumbleweed" anemone *Liponema brevicorne*, mobile predators *Neptunea-Buccinum* complex snails and *Sebastolobus* rockfish dominated there.

Biotope 16. Exhibited 64 % community similarity. Transects were all located on flat mud plains with greenish-black coarse sand at Site K (Figure 1), with a mean of 727 m (± SD 2.6) depth. Oxygen concentrations for these transects was not measured, however the water depth puts them in the OMZ (Figure 2). Mid-range temperatures were recorded. Low abundance and low diversity ($\bar{x}$ = 15.7 taxa ± SD 3.0, 1.1 m^{-2} ± SD 0.05) was observed. Nearly all organisms were mobile predators and scavengers and were represented by two species of shrimps and the snakehead eelpout *Lycenchelys crotalinus*. The sea cucumber *Pannychia* sp. 1, a mobile surface deposit feeder, was present as well.

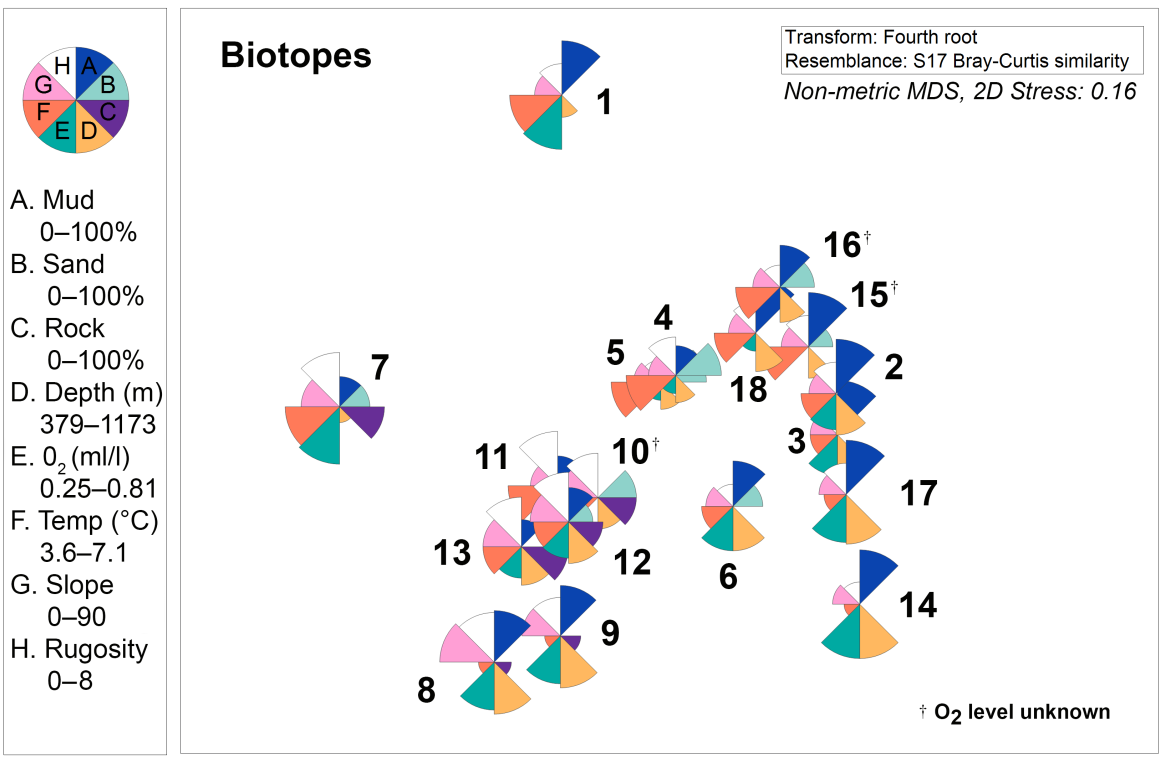

Figure 10. Segmented bubble plot demarking 18 biotopes. Plots are positioned in the non-metric multidimensional scaling (nMDS) ordination defining statistically significant SIMPROF biological community clusters with similarity > 60 %. Segments of each bubble plot are labeled A-H on the left of the figure and represent the abiotic factors of the biotope. The length of each segment shows the relative differences of the abiotic/environmental differences among biotopes. For example, biotope 1 has large % of mud, high temperature and oxygen. Data presented in Table 7 and Appendix C.

Table 8. Summary of 18 biotopes. Results of 18 groups derived from SIMPROF on Bray-Curtis similarity matrix of megafauna species and abundances from 91 quantitative transects. Biotope groups represent 70 (77 %) of the number of quantitative transects (n), where more than three transects made up a group and the mean number of species (Ave. No. spp.; averaged by transect) ranged from 10 to 46. Percent of animals are shown for Mobility categories (Mobile or Sessile) and amongst Trophic levels of suspension/filter feeders (SF), predators/scavengers (Pred), surface deposit feeders (SD), and subsurface deposit feeders (SSDF). OMZ for Biotopes 10, 15, and 16 indicates these transects had no measured O_2 levels but are presumed to be at OMZ levels based on depth. Similarity (%) within each group ranged from 61–80 % and details of each biotope are in Appendix C.

									Mobility		Trophic				
Biotope	n	Substrate	Ave. No. spp.	Density (m^{-2})	Slope (deg)	Depth (m)	O_2 ($ml\ l^{-1}$)	Temp (C)	Mobile	Sessile	SF	Pred	SDF	SSDF	Mixed
1	6	mud, hummocky	10.5	1.1	0-5	421	0.80	7.08	99.0	1.0	1.4	8.5	90.1	0.0	0.0
2	9	mud, hummocky	16.0	1.2	0-5	872	0.31	4.38	51.0	49.0	52.2	45.2	2.6	0.0	0.1
3	3	mud, hummocky	14.3	1.0	0-5	939	0.36	4.16	28.5	71.5	71.6	27.4	1.0	0.0	0.0
4	5	muddy coarse sand, cobble, mildly rugose	21.8	1.3	0-5	721	0.27	5.04	69.8	30.2	33.7	14.0	52.3	0.0	0.0
5	3	muddy coarse sand, flat	17.3	0.6	0-5	631	0.26	5.37	89.6	10.4	14.3	25.5	60.2	0.0	0.0
6	3	mud, flat	18.3	2.6	0-5	917	0.42	4.01	13.4	86.6	86.6	12.1	1.3	0.0	0.0
7	5	cobble (large), rugose	33.0	5.0	5-30	379	0.81	7.23	75.5	24.5	24.2	6.5	69.2	0.0	0.0
8	3	mud, some bedrock slabs, rugose	35.0	1.1	30-60	1111	0.50	3.63	71.7	28.3	27.7	51.6	20.6	0.0	0.0
9	3	mud with cobble, mildly rugose	37.0	1.0	5-30	1114	0.51	3.59	70.2	29.8	30.5	40.6	28.9	0.0	0.0
10	3	bedrock, rugose	41.0	6.7	5-30	697	OMZ	5.06	77.8	22.2	23.0	42.3	34.7	0.0	0.0
11	3	cobble, rugose	35.0	4.6	0-5	611	0.27	5.44	72.3	27.7	27.2	13.6	59.2	0.0	0.0
12	3	bedrock slabs, rugose	45.7	4.4	5-30	866	0.32	4.43	30.4	69.6	67.2	21.0	11.7	0.0	0.1
13	3	bedrock slabs, rugose	43.7	4.4	5-30	753	0.28	4.76	52.3	47.7	48.6	17.0	34.4	0.0	0.0
14	3	mud, flat	10.7	0.5	0-5	1173	0.52	3.59	97.8	2.2	60.2	31.9	7.9	0.0	0.0
15	3	mud, hummocky	25.0	5.2	0-5	693	OMZ	5.00	30.7	69.3	69.9	26.6	3.4	0.1	0.0
16	3	muddy coarse sand, flat	15.7	1.1	0-5	727	OMZ	4.86	96.5	3.5	4.2	86.2	9.6	0.0	0.0
17	6	mud, hummocky	14.0	0.5	0-5	1066	0.49	3.72	39.7	60.3	64.3	32.2	3.3	0.0	0.1
18	3	mud, hummocky	16.7	1.6	0-5	770	0.26	4.62	51.9	48.1	57.3	25.4	17.1	0.0	0.1

3.7 Pockmark Field Biological Communities

Megafauna. Thirty-three taxa in and around pockmarks were observed on the 18 transects from Sites B3 and R (Figure 1; Table 9). There were no significant differences in either density nor species richness of megafauna at either of the two sites. Both areas were characterized by the small cerianthid anemones, sea pens, sea stars, rockfish and eelpout fish. No recurring taxa were found exclusively inside or outside pockmarks. Rockfish were specifically assessed, and we found that at Site R (Figure 1) they were present in equal numbers inside and outside pockmarks. At Site B3, there were more rockfish inside pockmarks, but not significantly so. There was generally more pyrosome detritus inside pockmarks as well, but also not significantly so. There was a total of 16 drift kelp and eel grass and six items of marine litter in these transects; they were roughly evenly distributed inside and outside pockmarks.

Infauna. A total of 29 taxa were found in sediment samples taken with the pushcores (Table 9, Table 10). These included crustacean species of amphipods, cumaceans, ostracods, tanaids, and isopods, bivalve molluscs, and polychaete worms. Crustaceans comprised 55 % of abundance. The mean density (187 cm^{-3}) of infaunal organisms present inside pockmarks (n = 3), vs. outside pockmarks (n = 3), was not significantly different for any of the three individual pockmarks tested (all $p > 0.5$). As well, species richness did not significantly differ between pockmarks (Table 10). No recurring taxa were found exclusively inside or outside pockmarks. While there were no statistically significant differences in the diversity and density of infaunal organisms present inside vs. outside pockmarks, there was high variation for three species (two amphipods and a bivalve) at specific pockmarks indicating faunal patchiness.

Table 9. No significant differences (*p*) of t-tests were detected inside and outside (the two treatments) of pockmarks from video transect (megafauna) and pushcore (infauna) densities and species richness. Values were averaged per transect with ± equal to standard deviation. The number (n) of pockmarks sampled was three at two sites in the northern part of the study area. While six transects were conducted at each pockmark, with three transects inside and three outside), results were pooled for within each treatment since transects were contiguous.

Megafauna	**n**	**Inside**	**Outside**	***p***
Density (m^{-2})				
Site R (pockmark A, B, C)	3	209 ± 73	311 ± 138	0.343
Site B3 (pockmark A, B, C)	3	205 ± 76	248 ± 105	0.600
Species Richness				
Site R (pockmark A, B, C)	3	15.7 ± 2.1	14.3 ± 3.5	0.602
Site B3 (pockmark A, B, C)	3	14.0 ± 1.0	12.7 ± 1.2	0.205
Infauna	**n**	**Inside**	**Outside**	***p***
Density (cm^{-3})				
Pockmark A	3	5.7 ± 1.5	11.3 ± 3.5	0.14
Pockmark B	3	3.0 ± 1.7	7.7 ± 1.5	0.12
Pockmark C	3	2.3 ± 2.1	1.7 ± 1.5	0.18
Species Richness				
Pockmark A	3	5.0 ± 2.0	3.3 ± 0.6	0.20
Pockmark B	3	2.0 ± 1.0	4.3 ± 1.0	0.32
Pockmark C	3	1.7 ± 1.5	1.7 ± 1.4	1.00

Table 10. List of infaunal organisms identified from sediment samples by major taxonomic group.

Group	Species
Polychaeta	*Ophelina acuminata*
Polychaeta	Orbiniidae
Polychaeta	Paraonidae
Polychaeta	Dorvilleidae
Polychaeta	*Subadyte* sp.
Polychaeta	*Spiochaetopterus costarum* Complex
Polychaeta	*Prionospio* sp.
Polychaeta	Flabelligeridae
Polychaeta	*Aricidea (Allia) antennata*
Amphipoda	*Ampelisca unsocalae*
Amphipoda	*Byblis barbarensis*
Amphipoda	*Bathymedon sp.*
Amphipoda	*Monoculodes latissimanus*
Amphipoda	*Nicippe tumida*
Amphipoda	*Harpiniopsis epistomata*
Amphipoda	*Hippomedon* sp.
Cumacea	*Lampropidae* sp. F
Cumacea	*Eudorella arctica*
Cumacea	*Eudorella* sp.
Cumacea	*Leucon bishopi*
Cumacea	*Leucon magnadentata*
Isopoda	*Eurycope californiensis*
Isopoda	*Munnopsurus* sp. A
Tanaidacea	*Carpoapseudes caraspinosus*
Ostracoda	*Bathyleberis* sp.
Bivalvia	*Nuculana* juv.
Bivalvia	*Yoldiella nana*
Bivalvia	*Adontorhina lynnae*
Bivalvia	*Neilonella mexicana*

3.8 Result Highlights

- Rugose, hard substrate supported the highest number of taxa and densities.
- Soft substratum on 0–5 degree vertical slopes between 421–1066 m depth supported the lowest abundance and number of individual species of organisms.
- Greenish-black coarse sand occurred only in low oxygen regions on Santa Lucia Bank.
- There was no evidence of chemosynthetic biological communities within the study area.
- High and possibly ephemeral carbon flux to the seafloor during two of the three surveys and were observed with high abundances of ophiuroids and urchins that may have been transient aggregations.

- Soft substratum and the soft substratum pockmark fields were not significantly different from each other in terms of density nor species richness, but both were significantly different from hard substrate areas. While these two substrata can generally be treated as similar habitat in terms of species richness and density, the species present in soft substratum and pockmark fields only overlapped an average of 57 %.
- In this specific study where 70 % of quantitative sampling was conducted inside an OMZ, the presence of hard substratum was a better predictor of species richness and density than oxygen concentration.
- Individual pockmarks did not support unique megafauna and infauna and were similar in biodiversity and density to the communities just outside the six pockmarks sampled.

4 Discussion

These ROV observations provide documentation of the surficial geology and megafauna that characterize the seafloor off central California in and around areas identified for potential wind farm development. The abundance of benthic and demersal megafauna decreased with depth, while species richness remained relatively similar between 371–1173 m depth. This is a common pattern found on continental slopes (Rex 1981, Ramirez-Llodra et al. 2010). Rugose, hard substrate supported the highest number of taxa and densities. Hard substratum supported more than twice the number of megafaunal taxa and twice the density of organisms as soft substratum areas.

No large or abundant hard corals were observed during this study. Several hypotheses could explain the disparity in the size (and perhaps age) of the sessile fauna: 1) depth 2) temperature 3) oxygen levels 4) carbon and nutrient flux 5) fishing pressure 6) substratum type. Few data are available to inform us of localized current regimes and carbon flow to the seafloor at these locations, which can bring food and other nutrients to sessile suspension feeding animals, and may dictate coral distributions (Huff et al. 2013). While there is insufficient data to reject some of these hypotheses, we suspect that a combination of factors are likely to play a role. Hard substratum as deep as 1100 m was explored in this study, yet only a few hard corals were seen, and they were small (first author observation). In contrast, two nearby topographic highs (Davidson Seamount and Sur Ridge) both support more corals. Davidson Seamount is a hard substratum region to the northwest that supports large stands of corals including dense stands of the bubblegum coral, *Paragorgia arborea,* which were not observed in this study. *P. arborea* found on Davidson Seamount occur in deeper, more oxygen rich, cooler temperature water (1241–3040 m depth, $\bar{x}$ = 1291 ± SD 75, dissolved oxygen 0.85 ml l^{-1} ± SD 0.16, and temperature of 2.7 ºC ± SD 0.22; Jacobsen Stout et al. 2020). Sur Ridge supports *P. arborea* in locally high densities (826–1290 m depth, $\bar{x}$ = 1091 ± SD 154 (dissolved oxygen 0.53 ml l^{-1} ± 0.16, and temperature of 3.64 ± SD 0.44; Jacobsen Stout et al. 2020). *Isidella tentaculum* occurs at Sur Ridge as well from 747–1303 m depth with the largest and densest stands at a mean depth of 1107 m ± SD 0.147 (dissolved oxygen 0.55 ml l^{-1} ± SD 0.15 and temperature of 3.53 ± SD 0.33; Jacobsen Stout et al. 2020). Santa Lucia Bank exhibits evidence of trawling (this study), while Davidson Seamount and Sur Ridge do not (Jacobsen Stout et al. 2020). The exposed rocks on all three banks differ. Basalt is exposed on Davidson Seamount (Clague et al. 2009), Mesozoic age rocks of the Franciscan Formation are thought to be exposed on Sur Ridge (Greene et al. 1998) and Miocene aged rocks of the Monterey Formation occur on Santa Lucia Bank (McCulloch 1987, Nicholson et al. 1992). Decreased competence of the strata found in the study area may provide less favorable surfaces for attachment. Large sessile organisms probably fail to live long in the study area due to the relatively friable substratum and they are doomed to fall over when it finally erodes around them. In late 2020, E/V *Nautilus*, using ROV *Hercules* (led by NOAA Ocean Exploration and Research, Monterey National Marine Sanctuaries and others) explored a fault scarp south the of the areas we studied and located large corals and sponges at 1100 m depth (Duncan et al. 2021, Raineault et al. 2021). This area may be less likely to have been trawled, as it is more distant from Morro Bay. While the substratum looks generally similar in lithology to that we observed on Santa Lucia Bank, these dives were south of the Morro Fracture Zone and thus could be different. There appeared to be larger, less tabular boulders and megaclasts. With additional analyses underway, stable isotope samples, water column chemistry, and video from the area may provide some insight (Prouty et al. 2020).

Otherwise unobservable organisms (e.g., burrowing urchins) were detected by recording observations of biological detritus. We were able to establish that hummocky mud was frequently, if not always, harboring living burrowing heart urchins. Detrital data also allowed for the detection of potentially unique, specious biogenic habitat created by dead sponges.

Abundant biological detritus in the form of dead and dying pyrosomes, and to a much lesser extent salps, was present during the later portion of the study period. No pyrosomes were observed on the seafloor during the *R/V Western Flyer* cruise in February 2019, and only a dozen observations were made in the water column. On the central coast, dead and dying pyrosomes were first seen by MBARI in increased numbers at a recurrently-sampled site (Station M, 4000 m, southwest of the current study area) in the fall of 2012 (Kuhnz et al. 2020b). They were rarely observed anywhere off central California prior to 2012 (Jacobsen Stout et al. 2020). In June 2015, pyrosomes were present on the deep seafloor at Station M at nearly 100 % cover. There was another apparent "bloom" in March 2017. By 2019, MBARI was again observing them in very high densities in numerous areas along the coast of central California, including in this study, and to depths as shallow as 400 m. At least 30 different taxa feed on these midwater tunicates; they are eaten by anemones, snails, sea stars, crinoids, sea cucumbers, urchins and crabs. This large flux of carbon to the seafloor could potentially alter biological community composition, at least over the short-term.

Compared with the available information for the wider region to the north and south and at similar depths, the observed densities for fishes, megafaunal invertebrates, drift kelp and eel grass are similar (Vetter and Dayton 1999, Yoklavich et al. 2000, Love and Yoklavich 2006, Lindholm 2009, Hallenbeck et al. 2012, Huff et al. 2013, Shester et al. 2017, Whitmire et al. 2017, Jacobsen Stout et al. 2020, Kuhnz et al. 2020a, Raineault et al. 2021). There were very high abundances of brittle stars and sea urchins in places. These animals are known to form feeding and spawning aggregations and have been previously observed along the California coast (Lauzon-Guay and Scheibling 2007, Stöhr et al. 2012, Jacobsen Stout et al. 2020). Only one rare species was encountered for this region (the bony fish *Eretmichthys pinnatus*), and no organisms appeared to be undescribed species (Burton and Lundsten 2008, Burton et al. 2017, Burton and Lea 2019, Jacobsen Stout et al. 2020).

Oxygen minimum zones are worldwide features resulting in gradients in biological activity and vary with latitude globally. Low oxygen environments can lead to changes in species diversity and densities (Gooday et al. 2010, Koslow et al. 2011, Stewart et al. 2014, Breitburg et al. 2018). The current upper and lower OMZ boundaries in the study region were comparable to other central coastal California areas at similar depths (Gilly et al. 2013). About 70 % of quantitative data from this study were in the OMZ, thus this dataset provides baseline information on low dissolved oxygen concentration megafauna within the region (Figure 2). A paucity of species may have been anticipated within the OMZ, but 117 of the total observed 173 species (68 %) were observed. The highest diversity in the region was at 772 m depth on hard substratum near the core of the OMZ. While the oxygen levels in the study area are all relatively low, abundances were not consistently lower in the OMZ. Organism size and biomass may be a better indicator of low dissolved oxygen conditions, as was observed with the small-sized corals observed in this study. In the context of this study, the presence of hard substratum was a stronger predictor of species richness and density than oxygen levels

Biotope analysis allowed us to explain habitats using finer depth and substratum categories. Mud containing coarse sand occurred only in very low oxygen areas and supported unique biologic assemblages; hummocky mud supported somewhat different species than flat mud plains. The greater surface area associated with bedrock slabs found on sediment draped slopes sustained higher numbers of different species, perhaps by providing the wide variety of organisms numerous distinctive substrate and food options, allowing for resource partitioning. Substratum alone did not always predict which biological communities were present; small changes in depth supported different fauna. As an example, bedrock slabs at 753 m depth supported a different community than those at 866 m with similar temperature, oxygen, and slope; and hummocky mud at 693, 770, 872 and 939 m all supported different species groups.

The area and pockmarks were examined for gas release (Walton et al. 2021, Prouty and Baker 2020a, 2020b) and no evidence of chemosynthetic communities were found. The detailed examination of individual pockmarks and the areas just outside them did not reveal significant biological community differences for megafaunal or infaunal community compositions. Infaunal sampling was limited in that only two pockmarks were sampled in this study, and a larger sample size could potentially yield different results. The diversity and density of organisms within pockmark fields mirrored surrounding mud habitats with no pockmarks, suggesting that these areas can be treated as ecologically similar habitats. These two substrata seem to be similar habitat in terms of species richness and density, however the species present in soft substratum and pockmark fields are not identical and overlapped an average of 57 %.

5 Conclusions

Defining biotopes was an effective method to reveal high levels of community similarity and the abiotic factors that demarcated them. Although 80 % soft substrate, we observed differences in biological communities where as few as one measured environmental factor varied. The soft substratum individual pockmarks however did not support unique megafauna or infauna and were similar in biodiversity and density to the communities just outside them. In this study offshore Morro Bay, California, distinct groupings of biological communities in association with substrates are important for making marine planning decisions and designing future impact assessments. Potential impact studies conducted in the future should be evaluated in light of the observed high, and possibly ephemeral carbon flux to the seafloor and the high abundances of ophiuroids and urchins that may have been transient aggregations.

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Appendix A: Presumptive Taxa Observed from ROV Dives

Major groups represent phylum-level classifications unless otherwise noted. Organisms identified at high-level taxonomic categories represent one morphospecies unless otherwise noted in spp. Column. *Not observed on quantitative transects (not included in statistical analysis). MT: mobility type (S = sessile/functionally sessile M = mobile). FT: feeding type modified after Iken et al. 2001 (SF = suspension feeder; SDF = surface deposit feeder; SSDF = subsurface deposit feeder; PS = predator/scavenger; M = mixed categories). When taxa not directly referenced in Iken, inferred based on closest congener or at the group level or direct observations (LAK), No. spp. = estimated number of species included in the category. Taxonomic names and categories follow the World Register of Marine Species (http://www.marinespecies.org).

Phylum	Class	Order	Family	Presumptive Taxa	FT	MT	No. spp.
Foraminifera	Monothalamea	Xenophyophoroidea		Xenophyophoroidea	M	S	1
Porifera				*Porifera* spp.	SF	S	5+
	Demospongiae			*Demospongiae* sp. 1	SF	S	1
		Astrophorida	Theneidae	*Thenea muricata*	SF	S	1
		Poecilosclerida	Cladhorizidae	*Cladhorizidae* sp.	PS	S	1
				Cladorhizidae sp. A	PS	S	1
				Asbestopluma monitcola	PS	S	1
			Latrunculiidae	*Latrunculia (Latrunculia) austini*	SF	S	1
			Mycalidae	*Mycale*	SF	S	1
				Mycale sp. 1	SF	S	1
				Mycale sp. 2	SF	S	1
	Hexactinellida			*Hexactinellida spp.*	SF	S	5
				**Hexactinellida* sp. 4	SF	S	1
				**Hexactinellida* sp. 6	SF	S	1
		Hexactinosida	Aphrocallistidae	*Heterochone calyx*	SF	S	1
			Farreidae	*Farrea* sp.	SF	S	1
		Lyssacinosida	Rossellidae	*Acanthascinae* spp.	SF	S	5
				Acanthascinae sp. 1	SF	S	1
				Acanthascinae sp. 4	SF	S	1
				**Staurocalyptus*	SF	S	1
				?Staurocalyptus dowlingi	SF	S	1
				?Staurocalyptus solidus	SF	S	1
Cnidaria	Hydrozoa			*Hydroidolina sp.	SF	S	1
	Anthozoa			Scleractinia	SF	S	1
		Actiniaria		Actiniaria spp.	SF	S	3+
				Actiniaria sp. 1	SF	S	1
				Actiniaria sp. 2	SF	S	1
			Actinernidae	**Actinernus* sp.	SF	S	1
			Actiniidae	Actiniidae sp. 1	SF	S	1
				Isosicyonis	SF	S	1
			Actinostolidae	Actinostolidae spp.	SF	S	2
			Hormathiidae	Hormathiidae	SF	S	1
			Liponematidae	*Liponema brevicorne*	SF	M	1
		Alcyonacea		Alcyonacea	SF	S	1
				Octocorallia sp.	SF	S	1
			Alcyoniidae	*Heteropolypus ritteri*	SF	S	1

Phylum	Class	Order	Family	Presumptive Taxa	FT	MT	No. spp.
			Clavulariidae	Clavularia	SF	S	1
			Coralliidae	*Corallium	SF	S	1
			Isididae	**Isidella tentaculum*	SF	S	1
			Nephtheidae	*Gersemia juliepackardae*	SF	S	1
			Paragorgiidae	Paragorgiidae sp.	SF	S	1
			Plexauridae	*Swiftia kofoidi*	SF	S	1
				Swiftia simplex	SF	S	1
				Swiftia-1	SF	S	1
			Primnoidae	*Parastenella* sp.	SF	S	1
		Antipatharia	Schizopathidae	*Alternatipathes* sp.	SF	S	1
		Ceriantharia		Ceriantharia	SF	S	1
				Ceriantharia sp. 1	SF	S	1
				Ceriantharia sp. 2	SF	S	1
				Ceriantharia sp. 3	SF	S	1
		Corallimorpharia	Corallimorphidae	*Corallimorphus pilatus*	SF	S	1
				Corallimorpharia	SF	S	1
		Pennatulacea		Pennatulacea	SF	S	1
				Pennatulacea sp. 1	SF	S	1
			Anthoptilidae	*Anthoptilum grandiflorum*	SF	S	1
				**Anthoptilum lithophilum*	SF	S	1
			Funiculinidae	*Funiculina sp.*	SF	S	1
				Funiculina-Halipteris complex	SF	S	0
			Halipteridae	*Halipteris californica	SF	S	1
			Pennatulidae	*Pennatula sp.*	SF	S	1
				Pennatula phosphorea	SF	S	1
			Umbellulidae	*Umbellula lindahli*	SF	S	1
			Virgulariidae	*Virgulariidae sp.	SF	S	1
		Zoantharia		*Zoantharia	SF	S	1
		Siphonophorae	Rhodaliidae	Rhodaliidae sp.	SF	M	1
Platyhelminthes				*Platyhelminthes	SDF	M	1
Bryozoa				*Bryozoa	SF	S	1
Brachiopoda	Rhynchonellata	Rhynchonellida	Cancellothyrididae	?*Terebratulina sp.*	SF	S	1
Nemertea				Nemertea	SDF	M	1
Arthropoda				Caridea spp.	PS	M	2
				Paguroidea spp.	PS	M	2
	Malacostraca	Amphipoda		Amphipoda spp.	PS	M	2
		Decapoda	Epialtidae	*Chorilia longipes*	PS	M	1
			Hippolytidae	*Eualus macrophthalmus*	PS	M	1
			Lithodidae	*Lithodes couesi*	PS	M	1
				Neolithodes diomedeae	PS	M	1
				Paralomis spp.	PS	M	2
			Munididae	*Munida* sp. 1	PS	M	1
				Munida sp. 2	PS	M	1
				Munida quadrispina	PS	M	1
				Munida sp. A	PS	M	1
			Oregoniidae	*Chionoecetes tanneri*	PS	M	1
			Pandalidae	*Pandalopsis ampla*	PS	M	1
		Isopoda		Isopoda	PS	M	1

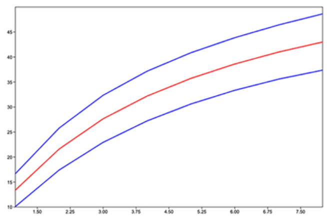
Phylum	Class	Order	Family	Presumptive Taxa	FT	MT	No. spp.
Annelida	Polychaeta	Phyllodocida	Polynoidae	*Harmothoe*	PS	M	1
			Polynoidae	Polynoidae spp.	PS	M	2
		Sabellida	Sabellidae	Sabellidae	SF	S	1
			Serpulidae	*Serpulidae	SF	S	1
				Echiura	SDF	M	1
				Polychaeta	SDF	M	1
Echinodermata	Asteroidea	Brisingida		Brisingida spp.	SF	M	2
		Forcipulatida	Asteriidae	*Rathbunaster californicus*	SDF	M	1
				Stylasterias forreri	PS	M	1
			Zoroasteridae	*Myxoderma*	SDF	M	1
				Myxoderma platyacanthum	SDF	M	1
				Myxoderma sacculatum	SDF	M	1
				Myxoderma sp. 1	SDF	M	1
		Notomyotida	Benthopectinidae	Benthopectinidae sp. 1	SDF	M	1
				Benthopectinidae sp. 2	SDF	M	1
		Paxillosida	Astropectinidae	*Dipsacaster eximius*	SDF	M	1
				Thrissacanthias penicillatus	SDF	M	1
		Spinulosida	Echinasteridae	**?Henricia sp.*	PS	M	1
		Valvatida	Goniasteridae	*Ceramaster*	PS	M	1
				Goniasteridae	PS	M	1
				Hippasteria californica	PS	M	1
				**Hippasteria phrygiana*	PS	M	1
				Mediaster aequalis	PS	M	1
			Poraniidae	*Poraniopsis inflata*	PS	M	1
			Solasteridae	*Crossaster borealis*	PS	M	1
				*?Solaster	PS	M	1
		Velatida	Myxasteridae	*Asthenactis fisheri*	PS	M	1
			Pterasteridae	Pterasteridae spp.	PS	M	2
				Asteroidea spp.	PS	M	3
				*Asteroidea sp. 1	PS	M	1
				*Asteroidea sp. 2	PS	M	1
	Crinoidea			*Comatulida sp.	SF	M	1
				Antedonoidea sp. 1	SF	M	1
				**Florometra serratissima*	SF	M	1
	Echinoidea	Camarodonta	Strongylocentrotidae	*Strongylocentrotus fragilis*	SDF	M	1
		Spatangoida	Schizasteridae	Spatangoida sp.	SSDF	M	1
	Holothuroidea			Holothuroidea	SDF	M	1
		Dendrochirotida	Psolidae	*Psolus squamatus*	SF	S	1
		Elasipodida	Elpidiidae	*Scotoplanes* sp. A	SDF	M	1
			Laetmogonidae	*Pannychia moseleyi*	SDF	M	1
				Pannychia sp. 1	SDF	M	1
		Synallactida	Stichopodidae	*Apostichopus leukothele*	SDF	M	1
				Holothuroidea -1	SDF	M	1
				Holothuroidea -2	SDF	M	1
				Holothuroidea -3	SDF	M	1
	Ophiuroidea			Ophiuroidea	SDF	M	1
				Ophiuroidea-1	SDF	M	1

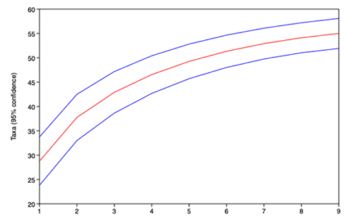
Phylum	Class	Order	Family	Presumptive Taxa	FT	MT	No. spp.
		Euryalida	Asteronychidae	*Asteronyx longifissus*	M	M	1
				**Asteronyx loveni*	M	M	1
			Gorgonocephalidae	*Gorgonocephalus eucnemis*	SF	M	1
		Ophiurida	Ophiacanthidae	Ophiacanthidae spp.	SDF	M	2
Mollusca	Bivalvia	Limida	Limidae	**Acesta sphoni*	SF	S	1
		Pectinida	Pectinidae	*Pectinidae sp.	SF	M	1
	Cephalopoda	Octopoda		Octopoda	PS	M	1
			Octopodidae	*Octopus californicus*	PS	M	1
			Opisthoteuthidae	*Grimpoteuthis* sp.	PS	M	1
				Opisthoteuthis sp. A	PS	M	1
	Gastropoda			Gastropoda spp.	PS	M	3
				Gastropoda -1	PS	M	1
				Gastropoda -2	PS	M	1
		Neogastropoda	Buccinidae	Neptunea-Buccinum Complex	PS	M	1
		Nudibranchia	Aeolidiidae	Aeolidiidae	PS	M	1
			Dendronotidae	**Dendronotus* sp.	PS	M	1
			Tritoniidae	*Tritonia tetraquetra*	PS	M	1
		Seguenziida	Eucyclidae	*Bathybembix* sp.	SDF	M	1
			Calliostomatidae	*Calliostoma platinum*	PS	M	1
	Polyplacophora			Neoloricata	SDF	M	1
Hemichordata	Enteropneusta		Harrimaniidae	*Saxipendium implicatum*	SDF	M	1
				Enteropneusta sp.	SDF	M	1
Tunicata (Subphylum)	Ascidiacea	Stolidobranchia	Styelidae	?C*nemidocarpa* sp.	SF	S	1
			Pyuridae	*Culeolus sp.*	SF	S	1
		Enterogona	Octacnemidae	**Megalodicopia hians*	PS	S	1
				Tunicata spp.	SF	S	2
Chordata	Actinopterygii			Actinopterygii spp.	PS	M	3
		Gadiformes	Macrouridae	Macrouridae	PS	M	1
				**Albatrossia pectoralis*	PS	M	1
				Coryphaenoides acrolepis	PS	M	1
				Coryphaenoides acrolepis-filifer complex	PS	M	0
				Merluccius productus	PS	M	1
			Moridae	*Antimora microlepis*	PS	M	1
		Ophidiiformes	Ophidiidae	*Eretmichthys pinnatus*	PS	M	1
		Osmeriformes	Alepocephalidae	*Alepocephalus tenebrosus*	PS	M	1
				Osmeridae	PS	M	1
		Perciformes	Embiotocidae	*Embiotocidae	PS	M	1
		Perciformes	Zoarcidae	*Bothrocara brunneum*	PS	M	1
				Lycenchelys crotalinus	PS	M	1
				Lycodapus fierasfer	PS	M	1
				Lycodes cortezianus	PS	M	1
				Lycodes diapterus	PS	M	1
		Pleuronectiformes	Pleuronectidae	*Embassichthys bathybius*	PS	M	1
				Glyptocephalus zachirus	PS	M	1

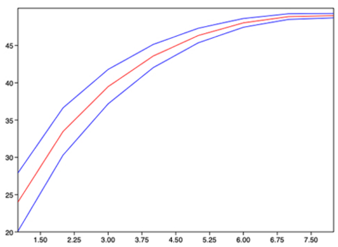
Phylum	Class	Order	Family	Presumptive Taxa	FT	MT	No. spp.
				Microstomus pacificus	PS	M	1
		Scorpaeniformes	Agonidae	*Xeneretmus latifrons*	PS	M	1
			Anoplopomatidae	*Anoplopoma fimbria*	PS	M	1
			Liparidae	*Careproctus kamikawai*	PS	M	1
				Careproctus melanurus	PS	M	1
				Liparidae-1	PS	M	1
				*Liparidae-2	PS	M	1
				Paraliparis cephalus	PS	M	1
			Sebastidae	*Sebastes aurora*	PS	M	1
				Sebastes diploproa	PS	M	1
				**Sebastes macdonaldi*	PS	M	1
				Sebastes melanostomus	PS	M	1
				**Sebastes phillipsi*	PS	M	1
				Sebastolobus alascanus	PS	M	1
				Sebastolobus altivelis	PS	M	1
				Sebastomus complex	PS	M	2
	Elasmobranchii	Carcharhiniformes	Scyliorhinidae	**Apristurus brunneus*	PS	M	1
				Parmaturus xaniurus	PS	M	1
		Rajiformes	Arhynchobatidae	**Bathyraja abyssicola*	PS	M	1
				Bathyraja kincaidii	PS	M	1
				Bathyraja trachura	PS	M	1
			Rajidae	*Beringraja rhina*	PS	M	1
	Holocephali	Chimaeriformes	Chimaeridae	*Hydrolagus colliei*	PS	M	1
	Myxini	Myxiniformes	Myxinidae	*Eptatretus* sp.	PS	M	1

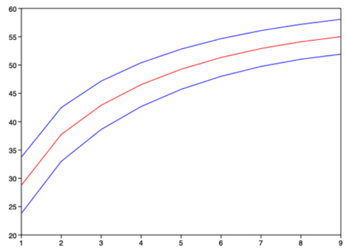
Appendix B: Species Accumulation Curves for Depth and Substratum Categories

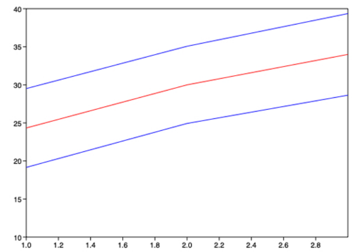
Red lines represent the species accumulation curve of transects for each depth vs. substratum category. Blue lines are the associated 95 % confidence intervals.



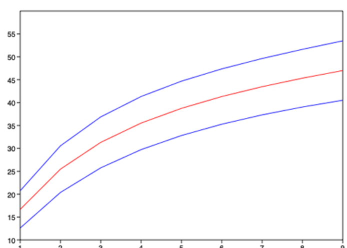


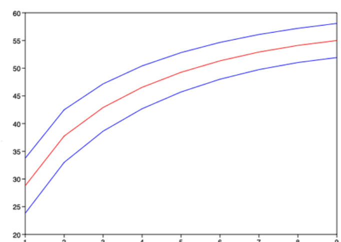


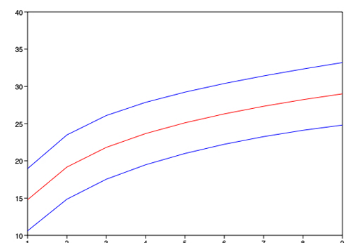


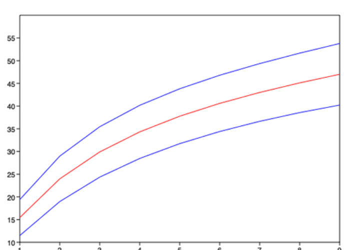


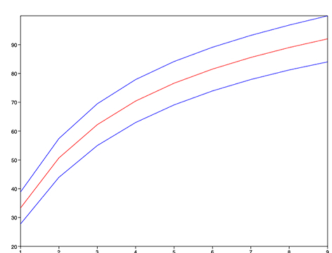
500–700 m hard substratum transects

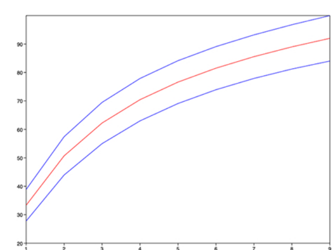










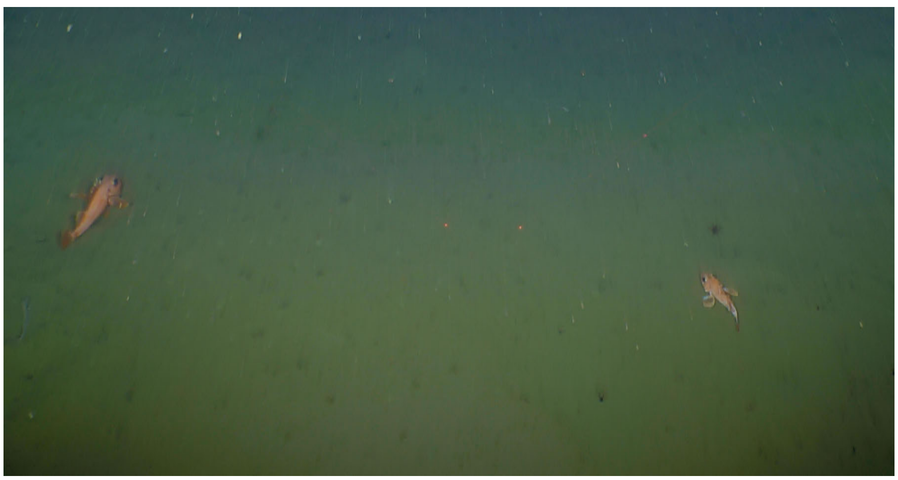


Appendix C: Biotope Summaries

Detailed biotope characteristics based on SIMPROF groups, which are derived from a Bray-Curtis similarity matrix of megafauna species and densities of quantitative transects. Results of these 18 groups represent 77 % of the quantitative transects where three or more transects were more similar to each other than to other transects. The defining biological community (species), surficial geological habitat and environmental characteristics, percent of animals in each mobility category and amongst trophic levels are shown. Average similarity refers to the similarity of the transects in the group. Mean density, similarity and standard deviation of similarity is listed for each species contributing to the top 60 % of organisms in the biotope. The percent contribution (Contrib%) and cumulative percent (Cum. %) for that species are listed. ± = standard deviation.

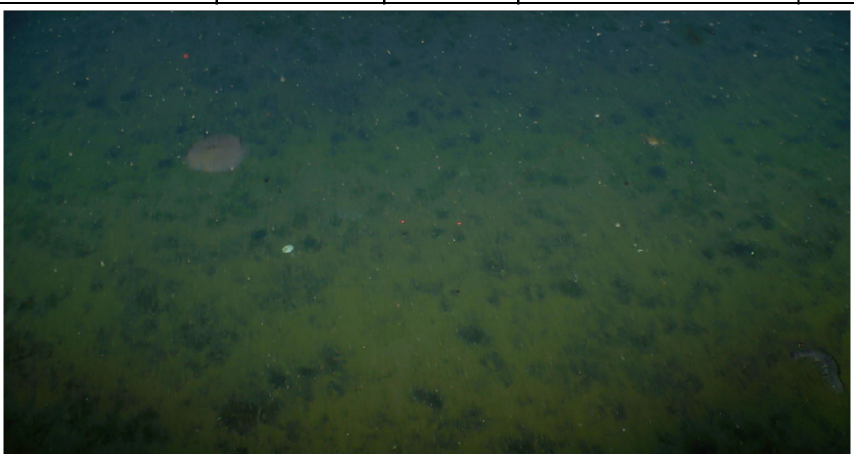
Biotope 1					
Average similarity: 60.51	**Slope (deg.)**	0-5	**Mobile %**	99.0	
Transects: 6	**Rugosity**	flat	**Sessile %**	1.0	
U-A, U-B, U-C, U-D, U-E, U-F	**Depth (m)**	421	**Suspension/Filter %**	1.4	
Substrate: mud, hummocky	**Oxygen (ml $^{-1}$)**	0.80	**Predator/Scavenger %**	8.5	
Mean no. species: 10.5 ± 1.7	**Temp (℃)**	7.08	**Surface deposit feeder %**	90.1	
Mean density (m^{-2}): 1.1 ± 0.8	**Salinity (PSU)**	34.27	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Myxoderma platyacanthum	1	24.99	11.35	41.29	41.29
Microstomus pacificus	0.33	7.57	8.4	12.5	53.8
Lycodes diapterus	0.29	5.28	1.32	8.73	62.52

Biotope 2					
Average similarity: 73.45	**Slope (deg.)**	0-5	**Mobile %**	51.0	
Transects: 9: B3-A, B3-B, B3-C,	**Rugosity**	flat	**Sessile %**	49.0	
B3-D, B3-E, B3-F, T-A, T-B, T-C	**Depth (m)**	872	**Suspension/Filter %**	52.2	
Substrate: Mud, hummocky	**Oxygen (ml $^{-l}$)**	0.31	**Predator/Scavenger %**	45.2	
Mean no. species: 16.0 ± 3.0	**Temp (℃)**	4.38	**Surface deposit feeder %**	2.6	
Mean density (m^{-2}): 1.2 ± 0.5	**Salinity (PSU)**	34.49	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.1	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ceriantharia sp. 2	0.86	13.00	9.34	17.69	17.69
Sebastolobus	0.66	10.38	11.56	14.14	31.83
Lycodapus fierasfer	0.60	8.73	5.34	11.89	43.72
Lycenchelys crotalinus	0.56	8.72	12.97	11.88	55.59
Caridea	0.50	6.98	4.77	9.50	65.10



Biotope 3					
Average similarity: 63.34	**Slope (deg.)**	0-5	**Mobile %**	28.5	
Transects: 3	**Rugosity**	flat	**Sessile %**	71.5	
R-A, R-B, R-C	**Depth (m)**	939	**Suspension/Filter %**	71.6	
Substrate: mud, hummocky	**Oxygen (ml $^{-1}$)**	0.36	**Predator/Scavenger %**	27.4	
Mean no. species: 14.3 ± 1.5	**Temp (℃)**	4.16	**Surface deposit feeder %**	1.0	
Mean density (m^{-2}): 1.0 ± 0.5	**Salinity (PSU)**	34.52	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ceriantharia sp. 2	0.88	14.94	10.68	23.59	23.59
Sebastolobus	0.6	10.61	9.58	16.75	40.34
Lycenchelys crotalinus	0.44	7.16	8.37	11.31	51.65
Neptunea-Buccinum Complex	0.37	6.24	11.49	9.85	61.5

Biotope 4					
Average similarity: 77.05	**Slope (deg.)**	0-5	**Mobile %**	69.8	
Transects: 5	**Rugosity**	flat	**Sessile %**	30.2	
H3-D, H6-A, H6-B, H7-A, H7-B	**Depth (m)**	721	**Suspension/Filter %**	33.7	
Substrate: muddy coarse sand	**Oxygen (ml $^{-l}$)**	0.27	**Predator/Scavenger %**	14.0	
Mean no. species: 21.8 ± 4.2	**Temp (℃)**	5.04	**Surface deposit feeder %**	52.3	
Mean density (m^{-2}): 1.3 ± 0.5	**Salinity (PSU)**	34.43	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ceriantharia sp. 2	0.7	7.51	9.24	9.75	9.75
Bathybembix	0.67	6.93	6.32	9	18.75
Pannychia moseleyi	0.62	6.91	7.49	8.97	27.72
Ceriantharia sp. 1	0.55	5.82	10.6	7.56	35.28
Sebastolobus	0.47	5.25	17.08	6.82	42.09
Myxoderma platyacanthum	0.42	4.66	9.26	6.04	48.14
Neptunea-Buccinum Complex	0.42	4.55	6.63	5.9	54.04
Caridea	0.39	4.35	13.26	5.64	59.68
Liponema brevicorne	0.36	3.9	4.38	5.06	64.75



Biotope 5					
Average similarity: 69.51	**Slope (deg.)**	0-5	**Mobile %**	89.6	
Transects: 3	**Rugosity**	flat	**Sessile %**	10.4	
H4-A, H4-B, H4-C	**Depth (m)**	631	**Suspension/Filter %**	14.3	
Substrate: muddy coarse sand	**Oxygen (ml $^{-l}$)**	0.26	**Predator/Scavenger %**	25.5	
Mean no. species: 17.3 ± 3.1	**Temp (℃)**	5.37	**Surface deposit feeder %**	60.2	
Mean density (m^{-2}): 0.6 ± 0.2	**Salinity (PSU)**	34.40	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	

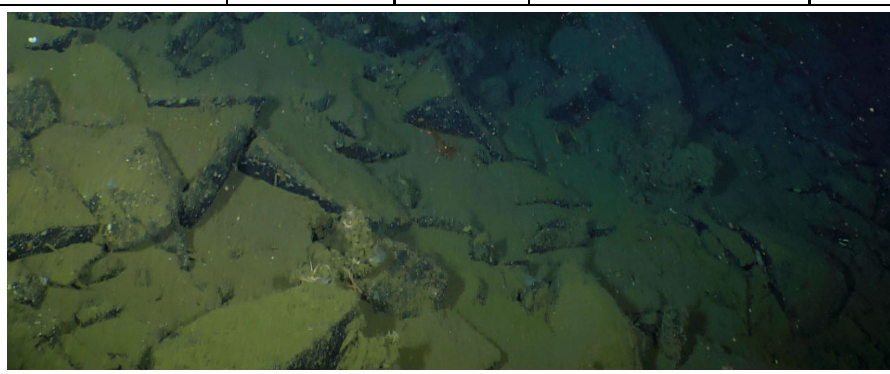
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Pannychia moseleyi	0.63	8.88	10.47	12.78	12.78
Bathybembix	0.61	8.62	480.49	12.41	25.18
Neptunea-Buccinum Complex	0.5	6.71	4.95	9.65	34.83
Ceriantharia sp. 1	0.46	6.67	7.73	9.6	44.43
Asteroidea	0.41	5.94	52.48	8.55	52.98
Sebastolobus	0.37	5.48	27.99	7.88	60.86

Biotope 6					
Average similarity: 75.89	**Slope (deg.)**	0-5	**Mobile %**	13.4	
Transects: 3	**Rugosity**	flat	**Sessile %**	86.6	
J1-A, J1-B, J1-C	**Depth (m)**	917	**Suspension/Filter %**	86.6	
Substrate: mud	**Oxygen (ml $^{-l}$)**	0.42	**Predator/Scavenger %**	12.1	
Mean no. species: 18.3 ± 0.6	**Temp (℃)**	4.01	**Surface deposit feeder %**	1.3	
Mean density (m^{-2}): 2.6 ± 0.2	**Salinity (PSU)**	34.53	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ceriantharia sp. 2	1.18	14.56	84.95	19.19	19.19
Neptunea-Buccinum Complex	0.57	7.04	28.13	9.27	28.46
Sebastolobus	0.54	6.57	96.24	8.65	37.11
Anthoptilum grandiflorum	0.56	6.53	12.3	8.61	45.72
Actiniidae sp. 1	0.51	5.8	6.43	7.65	53.37
Ceriantharia sp. 1	0.51	4.91	3.06	6.46	59.84
Isosicyonis	0.39	4.41	6.43	5.81	65.65

Biotope 7					
Average similarity: 80.40	**Slope (deg.)**	5-30	**Mobile %**	75.5	
Transects: 5	**Rugosity**	rugose	**Sessile %**	24.5	
Y1-B, Y1-C, Y4-A, Y4-B, Y4-C	**Depth (m)**	379	**Suspension/Filter %**	24.2	
Substrate: cobble (large)	**Oxygen (ml $^{-l}$)**	0.81	**Predator/Scavenger %**	6.5	
Mean no. species: 33 ± 1.8	**Temp (°C)**	7.23	**Surface deposit feeder %**	69.2	
Mean density (m^{-2}): 5.0 ± 0.2	**Salinity (PSU)**	34.28	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	

Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ophiacanthidae	1.12	6.83	4.47	8.5	8.5
Strongylocentrotus fragilis	1.01	6.31	6.47	7.85	16.34
?Terebratulina sp.	0.9	5.83	18.07	7.25	23.59
Rathbunaster californicus	0.74	4.96	37.93	6.17	29.76
Psolus squamatus	0.7	4.6	23.1	5.72	35.48
Porifera	0.68	4.37	10.73	5.43	40.91
Apostichopus leukothele	0.64	4.25	29.87	5.28	46.19
Henricia	0.44	2.86	21.38	3.56	49.75
Munida quadrispina	0.44	2.81	8.1	3.49	53.24
Sebastes melanostomus	0.42	2.69	9.88	3.35	56.59
Benthopectinidae-orange	0.48	2.68	3.25	3.33	59.92
Goniasteridae	0.42	2.64	9.8	3.28	63.2

Biotope 8					
Average similarity: 69.20	**Slope (deg.)**	30-60	**Mobile %**	71.7	
Transects: 3	**Rugosity**	rugose	**Sessile %**	28.3	
S-G, S-H, S-I	**Depth (m)**	1111	**Suspension/Filter %**	27.7	
Substrate: mud w/bedrock slabs	**Oxygen (ml $^{-l}$)**	0.50	**Predator/Scavenger %**	51.6	
Mean no. species: 35 ± 6.6	**Temp (℃)**	3.63	**Surface deposit feeder %**	20.6	
Mean density (m^{-2}): 1.1 ± 0.03	**Salinity (PSU)**	34.56	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Pandalopsis ampla	0.73	5.61	15.17	8.1	8.1
Ophiuroidea	0.58	4.34	15.74	6.27	14.37
Porifera	0.54	4.02	14.09	5.8	20.18
Farrea	0.5	3.87	16.79	5.59	25.77
Asteroidea	0.51	3.75	6.42	5.43	31.19
Holothuroidea	0.48	3.75	15.17	5.42	36.61
Munida sp. A	0.51	3.47	11.24	5.01	41.62
Tunicata	0.46	3.16	7.62	4.56	46.19
Heterochone calyx	0.41	3.07	10.74	4.44	50.63
Ophiacanthidae	0.43	2.85	7.62	4.12	54.75
Psolus squamatus	0.34	2.63	9.57	3.79	58.55
Chionoecetes tanneri	0.32	2.28	5.32	3.29	61.84



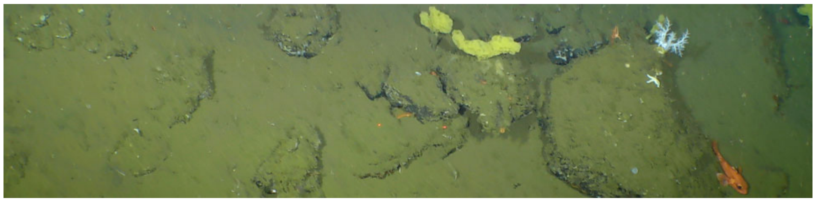
Biotope 9					
Average similarity: 65.04	**Slope (deg.)**	5-30	**Mobile %**	70.2	
Transects: 3	**Rugosity**	rugose	**Sessile %**	29.8	
S-D, S-E, S-F	**Depth (m)**	1114	**Suspension/Filter %**	30.5	
Substrate: mud with cobble	**Oxygen (ml $^{-1}$)**	0.51	**Predator/Scavenger %**	40.6	
Mean no. species: 37 ± 1.7	**Temp (°C)**	3.59	**Surface deposit feeder %**	28.9	
Mean density (m^{-2}): 1.0 ± 0.03	**Salinity (PSU)**	34.57	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Pandalopsis ampla	0.64	4.67	9.83	7.18	7.18
Asteroidea	0.55	3.99	12.09	6.14	13.32
Porifera	0.49	3.53	24.14	5.43	18.75
Ophiuroidea	0.57	3.44	2	5.28	24.03
Ceriantharia sp. 2	0.47	3.22	52.4	4.96	28.99
Sebastolobus	0.4	3.08	52.4	4.74	33.73
Sabellidae	0.43	2.88	11.97	4.43	38.15
Psolus squamatus	0.38	2.78	17.39	4.27	42.43
Actiniaria-wht	0.37	2.71	52.4	4.17	46.6
Hormathiidae	0.37	2.71	52.4	4.17	50.77
Actiniaria	0.36	2.61	8.49	4.01	54.77
Neptunea-Buccinum Complex	0.34	2.45	52.4	3.77	58.54
Paguroidea	0.34	2.45	52.4	3.77	62.31

Biotope 10					
Average similarity: 73.16	**Slope (deg.)**	5-30	**Mobile %**	96.5	
Transects: 3	**Rugosity**	rugose	**Sessile %**	3.5	
K-D, K-E, K-F	**Depth (m)**	697	**Suspension/Filter %**	4.2	
Substrate: bedrock	**Oxygen (ml $^{-l}$)**	unknown	**Predator/Scavenger %**	86.2	
Mean no. species: 41 ± 7.0	**Temp (℃)**	5.06	**Surface deposit feeder %**	9.6	
Mean density (m^{-2}): 6.7 ± 0.3	**Salinity (PSU)**	34.33	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Munida quadrispina	0.97	5.02	19.69	6.86	6.86
Sebastolobus	0.81	4.15	14.06	5.67	12.52
Pannychia sp. 1	0.76	3.77	13.22	5.15	17.67
Sabellidae	0.74	3.63	6.44	4.96	22.64
Ceriantharia sp. 2	0.71	3.51	10.31	4.8	27.43
Chorilia longipes	0.65	3.33	8.86	4.55	31.98
Caridea	0.65	3.09	15.1	4.22	36.2
Swiftia-pink-wht-polyps	0.59	2.92	90.51	3.99	40.19
Actinostolidae	0.51	2.66	15.1	3.63	43.82
Poraniopsis inflata	0.51	2.62	13.48	3.58	47.4
Ophiuroidea	0.52	2.51	5.77	3.43	50.83
Actiniaria-wht	0.48	2.32	5.59	3.16	53.99
Myxoderma	0.45	2.28	19.16	3.12	57.11
Bathybembix	0.5	2.11	4.38	2.88	59.99
Brisingida	0.43	2.06	5.09	2.82	62.81

Biotope 11					
Average similarity: 78.27	**Slope (deg.)**	0-5	**Mobile %**	72.3	
Transects: 3	**Rugosity**	rugose	**Sessile %**	27.7	
H5-A, H5-B, H5-C	**Depth (m)**	611	**Suspension/Filter %**	27.2	
Substrate: cobble (small)	**Oxygen (ml $^{-l}$)**	0.27	**Predator/Scavenger %**	13.6	
Mean no. species: 35 ± 1.7	**Temp (℃)**	5.44	**Surface deposit feeder %**	59.2	
Mean density (m^{-2}): 4.6 ± 0.2	**Salinity (PSU)**	34.39	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ophiuroidea	1.24	7.63	12.12	9.75	9.75
Sabellidae	0.92	5.44	14.98	6.95	16.71
Chorilia longipes	0.63	3.66	14.89	4.68	21.39
Sebastolobus	0.6	3.6	15.64	4.6	25.98
Pannychia moseleyi	0.54	3.25	14.58	4.15	30.13
Actinostolidae	0.53	3.21	22.43	4.1	34.23
Ceriantharia sp. 2	0.58	3.13	4.82	4	38.23
Neptunea-Buccinum Complex	0.49	3.11	13.83	3.98	42.21
Poraniopsis inflata	0.53	2.77	3.56	3.54	45.75
Porifera	0.48	2.77	55.91	3.54	49.28
Holothuroidea-1	0.48	2.64	4.82	3.37	52.65
Myxoderma platyacanthum	0.43	2.56	19.83	3.28	55.92
Swiftia-pink-wht-polyps	0.44	2.49	5.45	3.18	59.11
Microstomus pacificus	0.41	2.46	37.05	3.15	62.26

Biotope 12					
Average similarity: 74.41	**Slope (deg.)**	5-30	**Mobile %**	30.4	
Transects: 3	**Rugosity**	rugose	**Sessile %**	69.6	
H8-A, H8-B, H8-C	**Depth (m)**	866	**Suspension/Filter %**	67.2	
Substrate: bedrock slabs	**Oxygen (ml $^{-l}$)**	0.32	**Predator/Scavenger %**	21.0	
Mean no. species: 45.7 ± 8.3	**Temp (℃)**	4.43	**Surface deposit feeder %**	11.7	
Mean density (m^{-2}): 4.4 ± 1.2	**Salinity (PSU)**	34.49	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.1	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ceriantharia sp. 2	1.06	5.22	9.46	7.02	7.02
Thenea muricata	0.81	3.78	12.23	5.09	12.11
Poraniopsis inflata	0.78	3.71	9.28	4.99	17.09
Sabellidae	0.81	3.4	10.46	4.58	21.67
Sebastolobus	0.62	2.97	9.48	3.99	25.65
Porifera	0.64	2.95	12.03	3.96	29.61
Bathybembix	0.57	2.78	10.72	3.73	33.34
Cladhorizidae-single rachis	0.57	2.68	7.76	3.6	36.95
Psolus squamatus	0.57	2.68	9.71	3.6	40.54
Actinostolidae	0.52	2.48	10.21	3.34	43.88
Myxoderma platyacanthum	0.51	2.39	9.87	3.21	47.09
Actiniaria-wht	0.52	2.32	9.91	3.11	50.2
Pannychia moseleyi	0.49	2.22	8.09	2.99	53.19
Swiftia-pink-wht-polyps	0.51	2.17	6.85	2.91	56.1
Ophiacanthidae	0.57	2.16	11.84	2.9	59
Mycale sp. 1	0.43	2.02	12.21	2.72	61.72

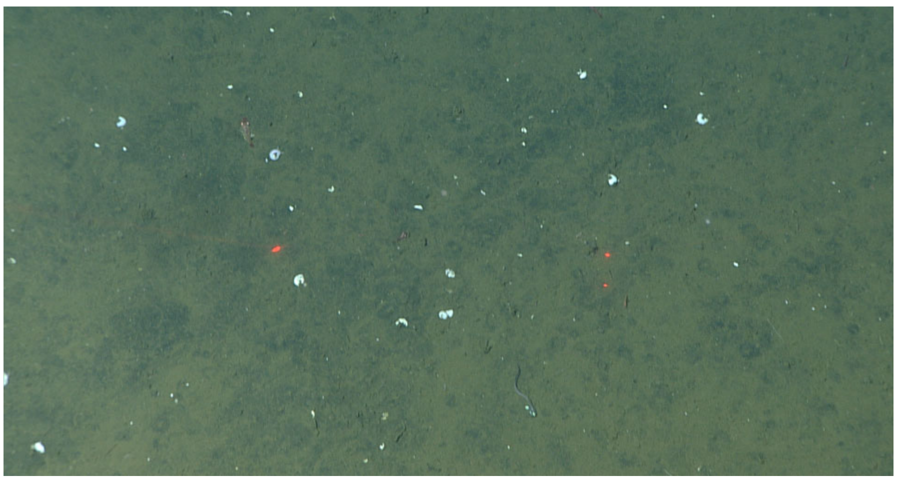
Biotope 13					
Average similarity: 74.79	**Slope (deg.)**	5-30	**Mobile %**	52.3	
Transects: 3	**Rugosity**	rugose	**Sessile %**	47.7	
H2-A, H2-B, H2-C	**Depth (m)**	753	**Suspension/Filter %**	48.6	
Substrate: bedrock slabs	**Oxygen (ml $^{-l}$)**	0.28	**Predator/Scavenger %**	17.0	
Mean no. species: 43.7 ± 2.1	**Temp (℃)**	4.76	**Surface deposit feeder %**	34.4	
Mean density (m^{-2}): 4.4 ± 0.1	**Salinity (PSU)**	34.45	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Sabellidae	0.83	3.65	11.71	4.88	4.88
Ceriantharia sp. 2	0.84	3.51	8.32	4.70	9.58
Pannychia moseleyi	0.81	3.47	7.66	4.64	14.22
Ophiacanthidae	0.74	3.32	6.00	4.44	18.67
Porifera	0.67	3.24	16.10	4.34	23.00
Poraniopsis inflata	0.71	3.07	4.26	4.10	27.11
Mycale sp. 1	0.62	2.87	9.61	3.84	30.95
Sebastolobus	0.59	2.87	19.68	3.84	34.78
Thenea muricata	0.58	2.47	5.89	3.30	38.08
Swiftia-pink-wht-polyps	0.50	2.44	20.02	3.27	41.35
Actiniaria-wht	0.49	2.35	10.99	3.14	44.49
Chorilia longipes	0.54	2.29	3.77	3.06	47.55
Neptunea-Buccinum Complex	0.45	2.19	13.01	2.92	50.47
Psolus squamatus	0.45	2.17	15.43	2.90	53.38
Bathybembix	0.53	2.16	2.65	2.89	56.27
Farrea	0.43	2.12	45.32	2.84	59.11
Demospongiae sp. 1	0.40	2.02	37.22	2.70	61.81



Biotope 14					
Average similarity: 62.67	**Slope (deg.)**	0-5	**Mobile %**	97.8	
Transects: 3	**Rugosity**	flat	**Sessile %**	2.2	
S-A, S-B, S-C	**Depth (m)**	1173	**Suspension/Filter %**	60.2	
Substrate: mud	**Oxygen (ml $^{-1}$)**	0.52	**Predator/Scavenger %**	31.9	
Mean no. species: 10.7 ± 2.1	**Temp (℃)**	3.59	**Surface deposit feeder %**	7.9	
Mean density (m^{-2}): 0.5 ± 0.02	**Salinity (PSU)**	34.57	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Liponema brevicorne	0.71	16.43	17.53	26.22	26.22
Neptunea-Buccinum Complex	0.5	13.01	12.14	20.76	46.98
Sebastolobus	0.49	12.95	8.6	20.66	67.64

Biotope 15					
Average similarity: 79.44	**Slope (deg.)**	0-5	**Mobile %**	30.7	
Transects: 3	**Rugosity**	flat	**Sessile %**	69.3	
Sites: G	**Depth (m)**	693	**Suspension/Filter %**	69.9	
Substrate: Mud, hummocky	**Oxygen (ml $^{-l}$)**	unknown	**Predator/Scavenger %**	26.6	
Mean no. species: 25 ± 4.4	**Temp (℃)**	5.00	**Surface deposit feeder %**	3.4	
Mean density (m^{-2}): 5.2 ± 0.2	**Salinity (PSU)**	34.33	**Sub-surface deposit %**	0.1	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Funiculina-Halipteris complex	1.22	9.52	13.17	11.99	11.99
Caridea	0.94	7.87	13.67	9.91	21.90
Ceriantharia sp. 2	0.89	6.99	14.36	8.80	30.70
Pennatula	0.84	6.65	11.77	8.37	39.07
Eualus macrophthalmus	0.64	4.92	12.38	6.19	45.26
Sebastolobus	0.58	4.78	13.92	6.02	51.28
Lycenchelys crotalinus	0.53	4.32	11.65	5.44	56.71
Myxoderma sp. 1	0.50	4.16	8.35	5.24	61.95

Biotope 16					
Average similarity: 63.94	**Slope (deg.)**	0-5	**Mobile %**	96.5	
Transects: 3	**Rugosity**	flat	**Sessile %**	3.5	
K-A, K-B, K-C	**Depth (m)**	727	**Suspension/Filter %**	4.2	
Substrate: muddy coarse sand	**Oxygen (ml $^{-l}$)**	unknown	**Predator/Scavenger %**	86.2	
Mean no. species: 15.7 ± 3.5	**Temp (°C)**	4.86	**Surface deposit feeder %**	9.6	
Mean density (m^{-2}): 1.1 ± 0.05	**Salinity (PSU)**	34.36	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.0	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Caridea	0.88	13.75	9.52	21.5	21.5
Lycenchelys crotalinus	0.67	10.13	9.27	15.84	37.34
Eualus macrophthalmus	0.5	8.02	9.65	12.54	49.88
Pannychia sp. 1	0.53	7.91	11.76	12.37	62.25



Biotope 17					
Average similarity: 68.13	**Slope (deg.)**	0-5	**Mobile %**	39.7	
Transects: 6	**Rugosity**	flat	**Sessile %**	60.3	
A-A, A-B, A-C, V-A, V-B, V-C	**Depth (m)**	1066	**Suspension/Filter %**	64.3	
Substrate: Mud, hummocky	**Oxygen (ml $^{-l}$)**	0.49	**Predator/Scavenger %**	32.2	
Mean no. species: 14 ± 3.0	**Temp (°C)**	3.72	**Surface deposit feeder %**	3.3	
Mean density (m^{-2}): 0.52 ± 0.02	**Salinity (PSU)**	34.56	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.1	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ceriantharia sp. 2	0.61	11.27	9.73	16.54	16.54
Sebastolobus	0.56	10.08	8.90	14.79	31.33
Pennatulacea sp. 1	0.50	7.79	3.43	11.43	42.76
Neptunea-Buccinum Complex	0.36	6.85	5.54	10.06	52.82
Lycenchelys crotalinus	0.35	6.37	5.17	9.34	62.17

Biotope 18					
Average similarity: 79.75	**Slope (deg.)**	0-5	**Mobile %**	51.9	
Transects: 3	**Rugosity**	flat	**Sessile %**	48.1	
B1-A, B1-B, B1-C	**Depth (m)**	770	**Suspension/Filter %**	57.3	
Substrate: Mud, hummocky	**Oxygen (ml $^{-l}$)**	0.26	**Predator/Scavenger %**	25.4	
Mean no. species: 16.7 ± 0.6	**Temp (℃)**	4.62	**Surface deposit feeder %**	17.1	
Mean density (m^{-2}): 1.6 ± 0.06	**Salinity (PSU)**	34.46	**Sub-surface deposit %**	0.0	
			Mixed feeder%	0.1	
Species	Mean abund.	Mean sim.	Sim/SD	Contrib%	Cum.%
Ceriantharia sp. 2	0.90	13.09	53.14	16.41	16.41
Myxoderma platyacanthum	0.72	10.23	31.63	12.83	29.24
Sebastolobus	0.60	8.38	76.82	10.51	39.76
Caridea	0.58	8.38	185.92	10.51	50.27
Funiculina-Halipteris complex	0.51	7.36	74.55	9.22	59.49
Lycenchelys crotalinus	0.48	6.82	139.82	8.55	68.04

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