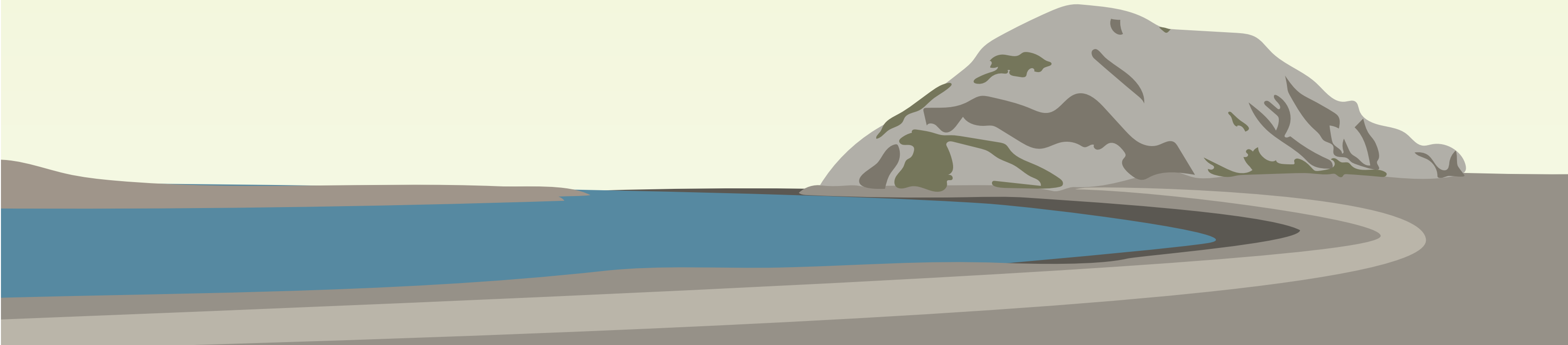
Prepared in cooperation with National Oceanic and Atmospheric Administration and Monterey Bay Aquarium Research Institute

California Deepwater Investigations and Groundtruthing (Cal DIG) I, Volume 3—Benthic Habitat Characterization Offshore Morro Bay, California



U.S. Geological Survey Open-File Report 2022–1035
Bureau of Ocean Energy Management OCS Study BOEM 2021–045

U.S. Department of the Interior
U.S. Geological Survey

California Deepwater Investigations and Groundtruthing (Cal DIG) I, Volume 3—Benthic Habitat Characterization Offshore Morro Bay, California

By Guy R. Cochrane, Linda A. Kuhnz, Lisa Gilbane, Peter Dartnell, Maureen A.L. Walton, and Charles K. Paull

Prepared in cooperation with National Oceanic and Atmospheric Administration and Monterey Bay Aquarium Research Institute

U.S. Geological Survey Open-File Report 2022–1035
Bureau of Ocean Energy Management OCS Study BOEM 2021–045

U.S. Department of the Interior
U.S. Geological Survey

U.S. Geological Survey, Reston, Virginia: 2022

Suggested citation:
Cochrane, G.R., Kuhnz, L.A. Gilbane, L., Dartnell, P., Walton, M.A.L., and Paull, C.K., 2022, California Deepwater Investigations and Groundtruthing (Cal DIG) I, volume 3—Benthic habitat characterization offshore Morro Bay, California: U.S. Geological Survey Open-File Report 2022–1035 [also released as Bureau of Ocean Energy Management OCS Study BOEM 2021–045], 18 p., https://doi.org/10.3133/ofr20221035.

Associated data for this publication:
Cochrane, G.R., Kuhnz, L.A., Gilbane, L., Dartnell, P., and Walton, M.A., 2022, Multibeam echo sounder, video observation, and derived benthic habitat data offshore of south-central California in support of the Bureau of Ocean Energy Management Cal DIG I, offshore alternative energy project: U.S. Geological Survey data release, https://doi.org/10.5066/P9QQZ27U.

ISSN 2331-1258 (online)

Acknowledgments

The Bureau of Ocean Energy Management (BOEM) funded this study under Intra-agency Agreement M17PG00021. The David and Lucile Packard Foundation (MBARI projects 901023 and 706004) funded the Monterey Bay Aquarium Research Institute (MBARI) participation in this study. Multibeam echo sounder data were collected by the National Oceanic and Atmospheric Administration (NOAA) hydrographic research vessels *Rainier* and *Fairweather* and funded in part by NOAA. The authors thank the science parties, the crews of all three cruises carried out during this study, and the remote operated vehicle pilots for research vessel *Bold Horizon*: Dale Graves, Frank Flores, and Lonny Lundsten (all of MBARI). Eve Lundsten (MBARI) compiled a bathymetry mosaic from all surveys available in the south-central California region that were used in figures 1–3 of this report and in numerous other project documents. Diana Watters and Tom Laidig (NOAA) provided helpful peer reviews. We remember Rear Admiral R.T. Brennan from NOAA Office of Coast Survey for his instrumental assistance in coordinating vessel data collection with both BOEM and the U.S. Geological Survey.

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)

Datum

Latitude and longitude in this report are relative to the North American Datum of 1983 (NAD 83).

Depth as referred to in this report is relative to mean lower low water (MLLW) from verified tides.

Abbreviations

BOEM	Bureau of Ocean Energy Management
BPI	bathymetry position index
Cal DIG	California Deepwater Investigations and Groundtruthing
CMECS	Coastal and Marine Ecological Classification Standard
CSMP	California Seafloor Mapping Program
DEM	digital elevation model
EEZ	Exclusive Economic Zone
E/V	exploration vessel
EXPRESS	Expanding Pacific Research and Exploration of Submerged Systems
FGDC	Federal Geographic Data Committee
GIS	geographic information system
MBARI	Monterey Bay Aquarium Research Institute
MBES	multibeam echo sounder
NOAA	National Oceanic and Atmospheric Administration
ROV	remotely operated vehicle
R/V	research vessel
SFC	seafloor character
USGS	U.S. Geological Survey

California Deepwater Investigations and Groundtruthing (Cal DIG) I, Volume 3—Benthic Habitat Characterization Offshore Morro Bay, California

By Guy R. Cochrane,[1] Linda A. Kuhnz,[2] Lisa Gilbane,[3] Peter Dartnell,[1] Maureen A.L. Walton,[1] and Charles K. Paull[2]

Abstract

Coastal and Marine Ecological Classification Standard (CMECS) geoform, substrate, and biotic component geographic information system (GIS) products were developed for the U.S. Exclusive Economic Zone (U.S. EEZ) of south-central California in the region of Santa Lucia Bank motivated by interest in development of offshore wind-energy capacity and infrastructure. The Bureau of Ocean Energy Management (BOEM), in coordination with the State of California and many other members of the California Task Force, issued calls for information in 2018 for the study area offshore of Morro Bay, California. The study area is in depths of 500 to 1,200 meters (m) and adjacent to a decommissioned nuclear power plant with a developed electric grid connection, and in an area of high wind resource. BOEM is the lead agency responsible for planning and leasing in the U.S. EEZ and funded this project to assess baseline conditions of, and the potential effects on, the seafloor environment. This project, carried out by the U.S. Geological Survey (USGS), resulted in three reports: one on biological analysis of seafloor video data, one on analysis of the geologic framework and hazards, and this report on seafloor habitat. The study area consists of 8,424 square kilometers (km^2) of multibeam echo sounder (MBES) data acquired during five surveys from 2016 to 2019. Remotely operated vehicle (ROV) video was acquired in 2019 to supervise the classification of the MBES data into habitats. Derivatives of the MBES data were classified into 16 unique biotopes, 6 substrate types, 28 modifier groups, and 22 geoforms. The study area substrate is predominantly soft sediment (mud and fine sand) covering 7,804 km^2 (92.7 percent) of the area. Mixed substrate areas on rocky banks, channel scarps, and the shelf break comprise 404 km^2 (4.8 percent) of the study area. Hard substrate areas are found predominantly on the tops and flanks of banks and on bank ridges that separate canyons incising the banks. Hard substrates comprise 211 km^2 of the study area (2.5 percent). After the bathymetry and backscatter raster images (rasters) were classified, manual editing was also done to remove noise artifacts. This effort was not completely successful and there are numerous erroneous small areas in the rasters that have been passed on to the CMECS polygon product. Nearly 120,000 annotations of organisms and their habitat were made from 25 video transects selected from 185 hours of ROV video. In total, 2,714 km^2 of seafloor were successfully assigned to biotopes. Some biotopes were assigned to separate areas spatially distant from the transects that define the biotope. Expected relations between physical habitat and biota such as the number of species and the substrate induration and rugosity were verified. Slope is typically a predictive variable and was used in the classification of habitat, but the ground truth used for biotic component analysis included very little steeply sloping area. Ground-truth ROV operations were reduced by the sea state; additional ground truth could improve the biotic results and increase confidence in the spatial distribution of classifications reported here.

Introduction

This mapping project was motivated because of interest by private companies and government at all levels to develop offshore wind energy capacity and infrastructure. The potential direct, indirect, and cumulative effects on the human, coastal, and marine environments are evaluated by the Bureau of Ocean Energy Management (BOEM) to make environmentally sound decisions about managing energy activities. Offshore wind development interacts with the seafloor over many kilometers and thus BOEM has a critical need for seafloor mapping and habitat characterization to assess baseline conditions of the seafloor environment to evaluate the environmental effects to seafloor habitats regionally. As a sibling research bureau in the Department of the Interior, the U.S. Geological Survey (USGS) is mandated with providing earth-science data acquisition and interpretation to provide baseline data to assess geology and habitat in BOEM regions of interest. BOEM, in coordination with the State of California and many other members of the California Task Force, issued two calls for information in 2018 for the study area (BOEM,

[1]U.S. Geological Survey.

[2]Monterey Bay Aquarium Research Institute.

[3]Bureau of Ocean Energy Management.

2018). The study area is in depths of 500 to 1,200 meters (m) and adjacent to a decommissioned nuclear power plant with a developed electric grid connection, and in an area of high wind resource (fig. 1). The project carried out by the USGS includes, in addition to the habitat analysis, an analysis and report on geologic framework and hazards (Walton and others, 2021) and a biological analysis of seafloor video data collected in the study area (Kuhnz and others, 2021).

Data acquired for this study included multibeam echo sounder (MBES) data (fig. 2) and remotely operated vehicle (ROV) video data. The MBES mapping covered a total of 8,424 square kilometers (km^2) and was accomplished on five

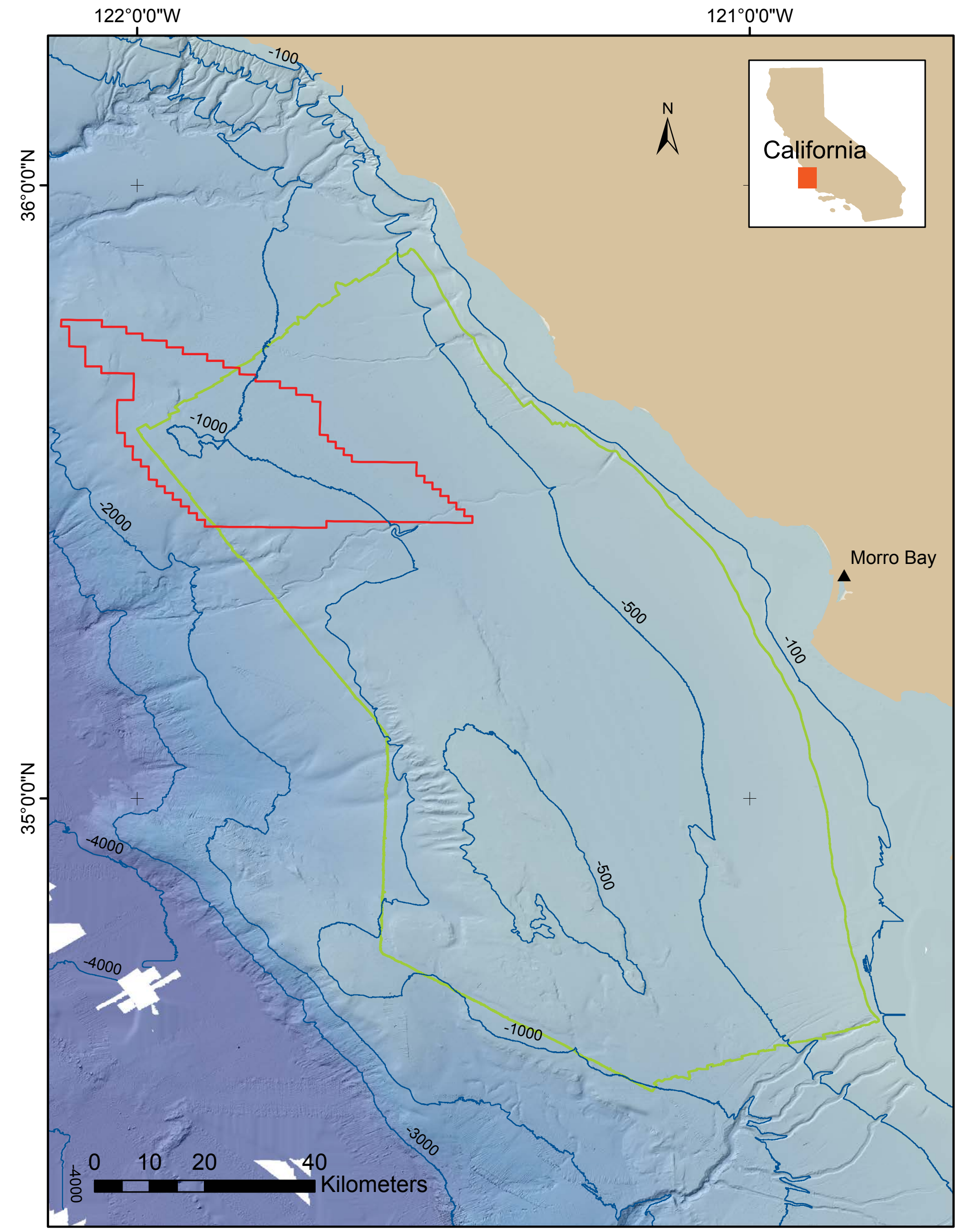


Figure 1. Map showing the California Deepwater Investigations and Groundtruthing (Cal DIG) I study area offshore Morro Bay, California. The area identified for potential future wind energy leases as of 2021 is outlined in red. This differs from the 2018 Bureau of Ocean Energy Management (BOEM) areas that were in effect when this study was designed. The area characterized using recent multibeam echo sounder data is outlined in green. Blue lines are depth contours in meters below sea level. Base from bathymetry acquired during this project and a 30-meter-resolution digital elevation model created by Monterey Bay Aquarium Research Institute for this project.

separate surveys over a 4-year period from 2016 through 2019 on cooperative cruises carried out by National Oceanic and Atmospheric Administration (NOAA) as part of the Expanding Pacific Research and Exploration of Submerged Systems (EXPRESS) collaboration (https://www.usgs.gov/centers/pcmsc/science/express-expanding-pacific-research-and-exploration-submerged-systems). The Scripps Institute of Oceanography surveyed a small portion of the area encompassing the Santa Lucia Bank Fault, an opportunistic effort in an area of USGS interest (fig. 3).

This report discusses the methods used and the mapping and habitat characterization products produced by the USGS for the study area, including a Coastal and Marine Ecological Classification System (CMECS) induration raster map

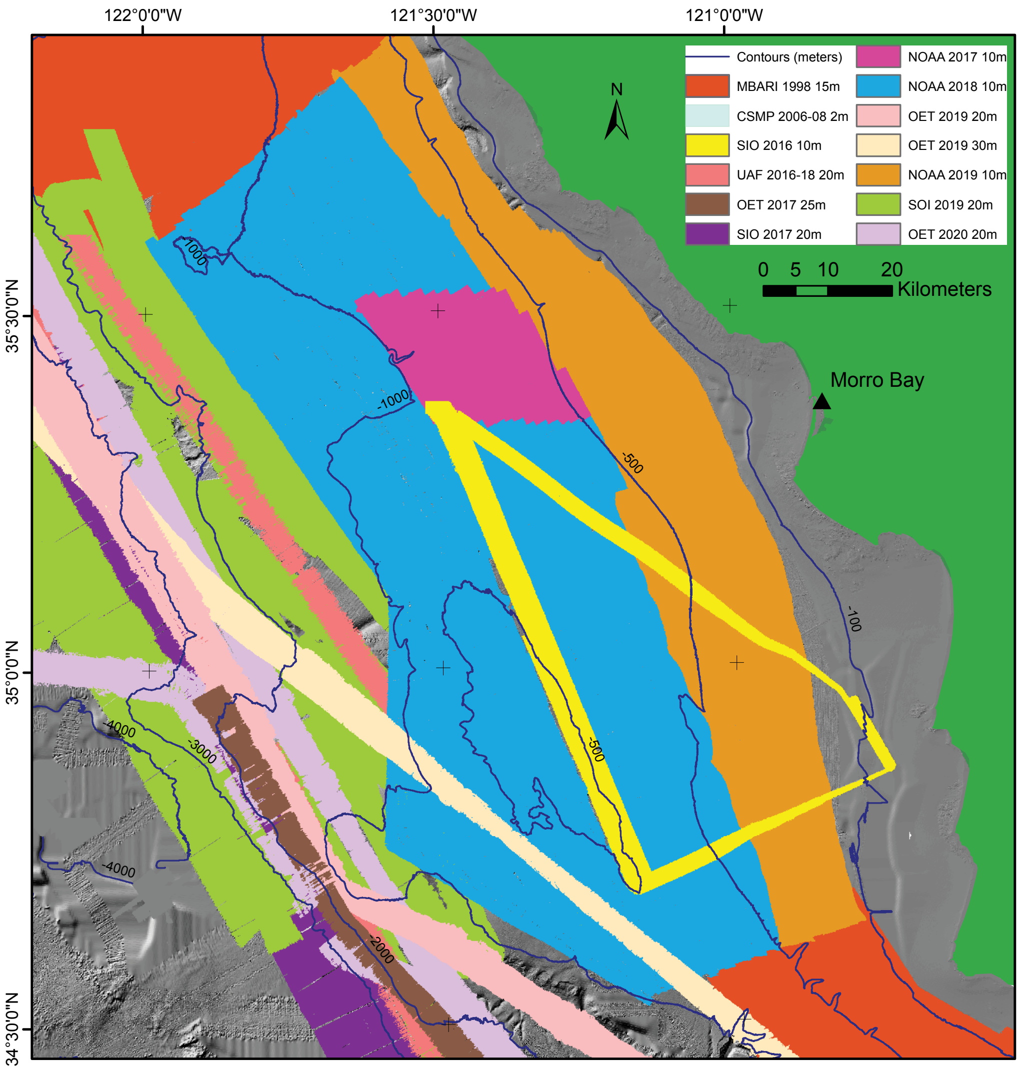


Figure 2. Map showing multibeam echo sounder (MBES) surveys in the vicinity of the study area, offshore Morro Bay, California, acquired with backscatter intensity data since 1998. The explanation has the survey operator, year of survey, and resolution in meters (m). The resolution of the data varies with depth and along strike, from 2 m depth in State waters to 30 m on the Ocean Exploration Trust 2019 transit. Gray areas indicate gaps in MBES data and are a shaded relief built from a 30-meter-resolution digital elevation model created by the Monterey Bay Aquarium Research Institute (MBARI) from bathymetry data that included older MBES and non-MBES data that lack backscatter intensity information. CSMP, California Seafloor Mapping Program; SIO, Scripps Institute of Oceanography; UAF, University of Alaska Fairbanks; OET, Ocean Exploration Trust; NOAA, National Oceanic and Atmospheric Administration.

(Cochrane, 2008) and a CMECS polygon shapefile map with geoform and biotic component attributes (Federal Geographic Data Committee [FGDC], 2012). These mapping products are available from Cochrane and others (2022) so that they can be incorporated into future geographic information system (GIS) and statistical analysis projects.

Purpose and Scope

The geographic scope of this study is focused on the south-central part of offshore California in the region surrounding the Santa Lucia Bank. Potential wind-energy developers indicated interest in areas offshore at depths of 500 to 1,200 m, far enough offshore to access higher wind potential and to reduce conflicts that could occur closer to shore. Previous high-resolution mapping was carried out in other Pacific outer continental shelf areas; however, MBES data were lacking in this part of the outer continental shelf offshore of south-central California. Given that the area is approximately 16,000 km^2 (larger than the State of Connecticut), and too costly to survey completely, data collection was carried out in an area offshore of Morro Bay, California, where onshore electric grid infrastructure is close (fig. 1). The intent is that this study can inform and provide regional context for future site-specific surveys.

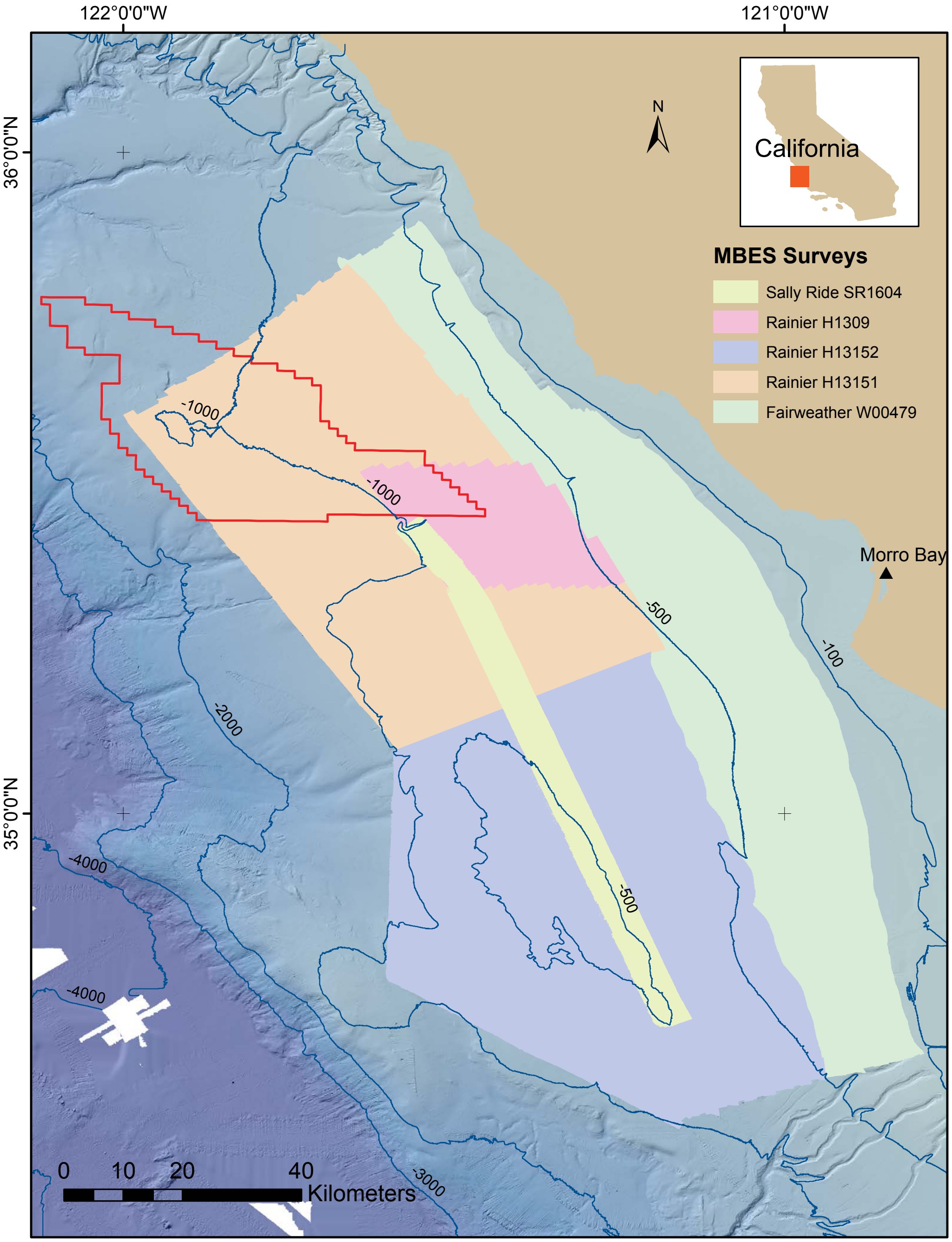


Figure 3. Map showing the extents of the California Deepwater Investigations and Groundtruthing (Cal DIG) I multibeam echo sounder (MBES) surveys offshore Morro Bay, California. The explanation shows ship and survey number arranged from oldest to most recent. The MBES mapping covered 8,424 square kilometers (km2) carried out by the National Oceanic and Atmospheric Administration (NOAA) as part of the Expanding Pacific Research and Exploration of Submerged Systems (EXPRESS) collaboration. The Scripps Institute of Oceanography surveyed a small portion of the area encompassing the Santa Lucia Bank Fault using research vessel (R/V) *Sally Ride* (2016). R/V *Rainier* (cruise H1309, 2017; cruises H13152 and H13151, 2018) and *Fairweather* (2019) data were collected by NOAA. The area identified for potential future wind energy leases as of 2021 is outlined in red. Base from a 30-meter.

Methods

The methodological approach used to characterize the physical benthic habitat in the study area has been used previously for a BOEM funded project on the Oregon outer continental shelf off Coos Bay (Cochrane and others, 2017). MBES bathymetry and backscatter data were acquired and used to design a remote operated vehicle (ROV) seafloor video ground-truth survey. Physical habitat and biota were cataloged during the video survey and subsequently used to supervise the classification of the MBES data into physical habitat and biotic assemblage maps. Biotic analysis for this study was done by Monterey Bay Aquarium and Research Institute (MBARI) and is not identical in methodology to the Oregon project methodology (Kuhnz and others, 2021). Details of each phase of the data acquisition and analysis are described in the following sections.

Multibeam Echo Sounder (MBES) Surveys

MBES data (with backscatter intensity information) have been acquired in the south-central California region by nine entities starting with the 1998 surveys by MBARI north and south of the project area (fig. 2). In California State waters, data were acquired by Fugro, California State University Monterey Bay, and the USGS for the California Seafloor Mapping Program (CSMP) (Johnson and others, 2017). There is a gap in modern MBES data between the CSMP data and NOAA data acquired in 2019. In waters deeper than 1,000 m, there are other gaps resulting from piecemeal mapping done by ships equipped with MBES operated by the Ocean Exploration Trust, Scripps Institute of Oceanography, Schmidt Ocean Institute, and the University of Alaska Fairbanks during transits to other areas. Some of the transit-acquired data have a low signal-to-noise ratio and intermittent signal that may be due to higher than optimal ship speed or poor sea state during the transits. The resolution of the data varies with depth and along strike, from 2 m depth in State waters to 30 m on the Ocean Exploration Trust 2019 transit (fig. 2). When using MBES data to classify the substrate and geomorphology of the seafloor, numerically it is necessary to use data of one resolution with a signal-to-noise ratio that allows features to be distinguishable.

The MBES data used in this study were acquired on five separate surveys over a 4-year period (fig. 3) and processed to 10 m resolution. A small MBES swath was mapped during a 2016 shakedown cruise of Scripps research vessel (R/V) *Sally Ride* (cruise SR1604) over a fault of interest to the USGS called the Santa Lucia Bank Fault (McCulloch, 1987). The NOAA R/V *Rainier* survey H1309 (2017) took advantage of a time gap during hydrographic surveys. Survey areas H13151 and H13152 were completed on a joint NOAA-USGS cruise of R/V *Rainier* in August and September 2018 (USGS field activity cruise 2018–641–FA). This joint operation concurrently collected multichannel seismic profiles (and chirp seismic profiles, weather permitting) for sub-bottom geophysical analysis of structure and stratigraphy. A discussion of sub-bottom geophysical analysis of the project data is in a separate report by Walton and others (2021). The most recent survey was done by NOAA R/V *Fairweather* (survey W00479) in 2019 using time away from NOAA's hydrographic mapping mission in 2019. The final total mapped area for this study was 8,424 km^2.

The USGS processed all bathymetry data using Caris HIPS to 10-m resolution. Backscatter data were processed using Caris SIPS to 10-m resolution. Backscatter from surveys H1309, H13151, and H13152 were processed by NOAA, and surveys SR1604 and W00479 were processed by USGS. The latter NOAA cruise, W00479, was not included in the original project plan but processed by USGS to be included in this analysis. MBES data in the region collected prior to 2016 were not used in this analysis because the lower resolution of the data made it incompatible in a numerical classification of geoforms.

The five separate bathymetry and backscatter intensity rasters were mosaicked into single rasters. The backscatter intensity rasters were first normalized as much as possible so that backscatter values matched in areas of overlap. Normalization was done by shifting the backscatter intensity value distribution for each survey using the Esri ArcGIS reclassify tool (https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/reclassify.htm). This effort was not completely satisfactory because a reclassification producing a match in one area of overlap did not produce a match in all areas of overlap. The backscatter intensity is not used to create many substrate classes, as explained below in the "CMECS Induration Classification" section.

Video Survey

With the processed MBES data in hand, a video survey was designed to ground truth the study area. The design of the survey is described in detail by Kuhnz and others (2021) and is based on preliminary models of the substrate and terrain derived from the MBES data. The goal of habitat video surveys is to transect the varying areas of MBES backscatter intensity, depth, and slope to develop supervision statistics for a final characterization of the physical habitat and biota in the area.

Multiple video surveys of the seafloor were combined from three separate cruises in the study area. A joint USGS-BOEM-MBARI cruise, which took place September 19–26, 2019, on Endurance Exploration Group, Inc., R/V *Bold Horizon* (USGS cruise 2019–642–FA), focused on carrying out biological surveys using MBARI's MiniROV (dives M137–148). Additional surveys were carried out on February 2–14, 2019 (dives D1120–1131), and November 1–11, 2019 (dives D1202–1217), using MBARI's R/V *Western Flyer* and ROV *Doc Ricketts* (Kuhnz and others, 2021).

In addition to ground truthing high and low backscatter areas and areas of varying slope, the video transects were distributed over several depth zones (Kuhnz and others, 2021). Circalitoral (30–200 m), mesobenthic (200–1,000 m), and bathybenthic (1,000–4,000 m) are CMECS standard depth zones. For biotic analysis, the mesobenthic zone was subdivided into five additional zones: (1) 200–300, (2) 300–500, (3) 500–700, (4) 700–900, and (5) 900–1,000 m (fig. 4). The original project design did not include the R/V *Fairweather* W00479 area (fig. 3), but two transects were done in that area because weather did not permit operations in deeper water. However, because the W00479 survey was done after the video ground-truth survey, there were no transects in the shallowest two benthic zones. In all, 185 hours of video were acquired covering 46.8 transect kilometers of seafloor for biotic analysis. Seafloor observations from an additional video transect in the southwestern part of the study area, done by the Ocean Exploration Trust, Inc., on the exploration vessel (E/V) *Nautilus* expedition 123 dive H1831 (Raineault and others, 2021), were also used in this study for physical habitat ground truthing. This video was not available in time for biotic assemblage analysis, but the physical habitats are included in the ground-truth observation shapefile by Cochrane and others (2022).

MBARI analyzed the video to catalog the substrate, terrain, and the assemblage of organisms that occupy the various areas (Kuhnz and others, 2021). The observations of physical habitat follow the method of Tissot and others (2006) and Greene and others (1999) but use point observations instead of lengths of transect. A primary substrate type is considered to cover 50 percent or more of the area in view; the secondary substrate type covers an area greater than 25 percent and less than 50 percent (FGDC, 2012). Grain-size categories are based on those of Folk (1954). The MBARI video observations are published as a point shapefile by Cochrane and others (2022).

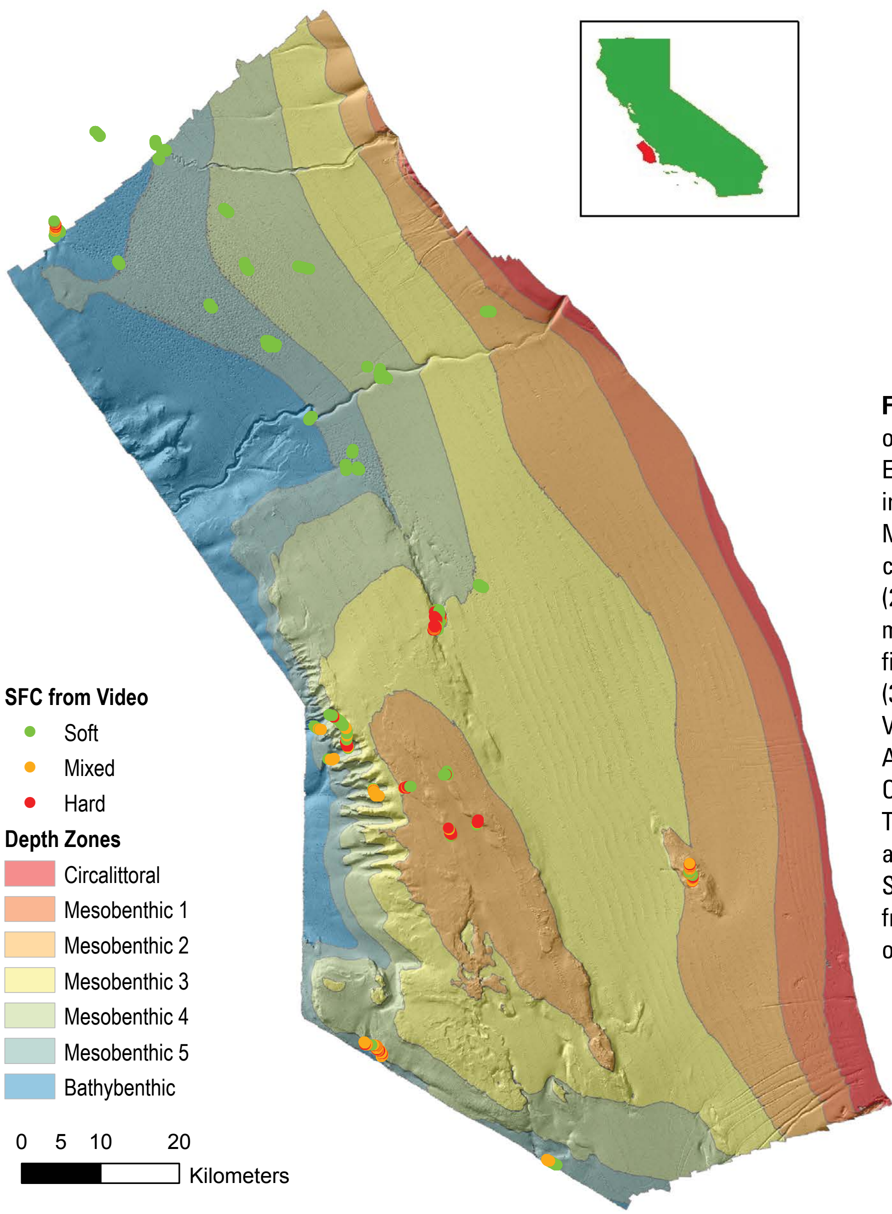


Figure 4. Map showing depth zones and video observations of seafloor Coastal and Marine Ecological Classification Standard (CMECS) induration used for analysis for this study, offshore Morro Bay, California. CMECS depth zones are circalitoral (30–200 meters [m]), mesobenthic (200–1,000 m), and bathybenthic (1,000–4,000 m). The mesobenthic zone was subdivided into five additional zones: (1) 200–300, (2) 300–500, (3) 500–700, (4) 700–900, and (5) 900–1,000 m. Video observations shown include Monterey Bay Aquarium and Research Institute (MBARI) and Ocean Exploration Trust, Inc., collected transects. The MBARI video observations are published as a point shapefile by Cochrane and others (2022). SFC, seafloor character. Shaded relief derived from bathymetry published by Cochrane and others (2022).

MBARI substrate observations were translated into CMECS induration classes by USGS for use as classification supervision (table 1). From this information, it is possible to supervise a final classification of the substrate and terrain for the entire mapped area, and using the associations developed between biotic groups and the physical habitat attributes, to generate the spatial extent of the biotic groups as described in the “Results” section below.

Table 1. Offshore Morro Bay, California, study area video observation combinations and the induration value assigned to the seafloor (fig. 4).

[Interfaces were not assigned substrate types. Some observations were not assigned values for one or more of the attributes where a secondary substrate, slope, or rugosity did not exist or could not be determined visually. A primary substrate type is considered to cover 50 percent or more of the area in view; the secondary substrate type covers an area greater than 25 percent and less than 50 percent (Federal Geographic Data Committee [FGDC], 2012). Grain-size categories are based on those of Folk (1954). —, no data; CMECS, Coastal and Marine Ecological Classification Standard]

Primary substrate type	Secondary substrate type	Slope (degrees)	Rugosity	Induration (CMECS class)
Mud	Mud	0–5	Flat	3
Mud	Coarse sand	0–5	Flat	3
Mud	Mud	30–60	Flat	3
Mud	Sand	5–30	Flat	3
Mud	Mud	5–30	Flat	3
Boulder	Mud	0–5	Flat	2
Cobble	Mud	0–5	Flat	2
Mud	Coarse sand	30–60	Flat	2
Mud	Cobble	30–60	Flat	2
Mud	Boulder	30–60	Flat	2
Pebble	Mud	0–5	Flat	2
Mud	Cobble	0–5	Flat	2
Interface	—	0–5	Flat	2
Interface	—	—	Flat	2
Coarse sand	Pebble	5–30	Flat	2
Cobble	Bedrock	5–30	Flat	2
Cobble	Mud	5–30	Flat	2
Mud	Cobble	5–30	Flat	2
Cobble	Mud	30–60	Rugose	2
Mud	Cobble	30–60	Rugose	2
Cobble	Mud	0–5	Rugose	2
Mud	Cobble	0–5	Rugose	2
Mud	Mud	0–5	Rugose	2
Mud	Mud	30–60	Rugose	2
Mud	Coarse sand	0–5	Rugose	2
Coarse sand	Coarse sand	30–60	Rugose	2
Cobble	Mud	Unknown	Rugose	2
Cobble	Cobble	30-60	Rugose	2
Interface	—	—	—	2
Mud	Bedrock	30–60	Rugose	1
Bedrock	Mud	30–60	Rugose	1
Boulder	Mud	30–60	Rugose	1
Cobble	Bedrock	30–60	Rugose	1
Bedrock	Mud	0–5	Rugose	1
Mud	Bedrock	0–5	Rugose	1
Mud	Boulder	0–5	Rugose	1
Mud	Boulder	30–60	Rugose	1

Table 1. Offshore Morro Bay, California, study area video observation combinations and the induration value assigned to the seafloor (fig. 4).—Continued

Primary substrate type	Secondary substrate type	Slope (degrees)	Rugosity	Induration (CMECS class)
Boulder	Boulder	0–5	Rugose	1
Boulder	Cobble	30–60	Rugose	1
Bedrock	Bedrock	60–90	Rugose	1
Bedrock	Mud	60–90	Rugose	1
Bedrock	Bedrock	30–60	Rugose	1
Interface	—	30–60	Rugose	1
Boulder	mud	0–5	Rugose	1
Interface	—	30–60	Rugose	1
Bedrock	—	30–60	Rugose	1
Bedrock	Mud	Unknown	Rugose	1
Bedrock	Bedrock	Unknown	Rugose	1
Bedrock	Bedrock	0–5	Rugose	1
Bedrock	Cobble	30–60	Rugose	1
Bedrock	Bedrock	5–30	Rugose	1
Bedrock	Mud	5–30	Rugose	1
Boulder	Mud	5–30	Rugose	1
Mud	Bedrock	5–30	Rugose	1
Mud	Boulder	5–30	Rugose	1
Bedrock	—	—	—	1

CMECS Induration Classification

The CMECS induration raster is a three-substrate classification suitable for inclusion in statistical analyses for species distribution models and other habitat management issues. It is based on the MBES bathymetry and backscatter data and preserves the resolution of those rasters allowing a one-to-one stacking of the rasters in an analysis stack. The three substrate classes are: (1) soft (mud and fine sand), (2) mixed (coarse sand, gravel, cobble, and low relief rock outcrop), and (3) hard (boulder, megaclast, and rugged rock outcrop). The induration classification was produced using video-supervised maximum likelihood classification of the bathymetry and backscatter intensity from the MBES survey, following the method described by Cochrane (2008).

This method is based on statistics gathered from a stack of rasters in small polygonal areas of known CMECS induration. The ground-truth video observation points guide the design of this polygon supervision shapefile. Rasters of three variables were used for this classification: (1) backscatter intensity, (2) slope, and (3) bathymetry position index (BPI). The BPI inside and outside radii were 10 and 40 m, respectively. The BPI calculation was done using the Benthic Terrain Modeler tool in Esri ArcMap (Wright and others, 2005). Maximum likelihood classification compares the variable values for each pixel and chooses the class that the pixel is closest to in a multivariable space. The analysis was done in Esri ArcMap version 10.7.

MBES data collected for this study suffered from noise and signal loss during acquisition. Headings were north-northwest–south southeast, and the north-northwest tracks were facing almost directly into the swell. Large swell states likely caused noise either by overwhelming the motion sensing system or by cavitation around the transducer. Figure 5 shows shaded relief and backscatter intensity data from an area of muddy flat seafloor with genuine pockmarks (Paull and others, 2002). The shaded relief reveals areas of false highs and lows that the numerical analysis converts into areas of ruggedness. The backscatter intensity shows false low-backscatter stripes that the numerical analysis converts into soft bottom. The backscatter intensity example also shows the variation in values related to processing of the data and is not related to genuine changes in seafloor induration. After the bathymetry and backscatter rasters were classified, a majority filter was used to eliminate some of the small areas of less than eight pixels, most of which were derived from noise. Hand editing in Esri ArcScan was also done to remove noise artifacts. This effort was not completely successful and there are numerous erroneous small areas in the raster that have been passed on to the CMECS polygon product.

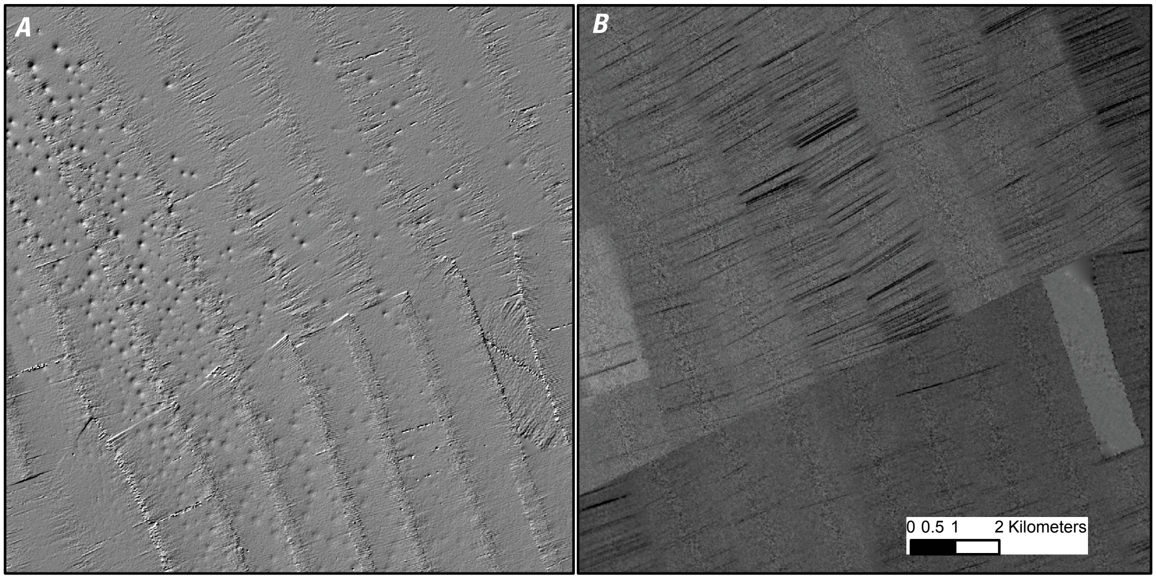


Figure 5. Images from the offshore Morro Bay, California, study area, showing the effects of ocean-swell generated noise on the Coastal and Marine Ecological Classification Standard (CMECS) induration results (see fig. 7 for location of images). *A*, The shaded relief reveals areas of false highs and lows that the numerical analysis converts into areas of ruggedness. Vertically exaggerated shaded relief (1.5×) shows false ridges and troughs from an area of muddy flat seafloor with genuine large (100 meter [m] radius) pockmarks (Paull and others, 2002). Shaded relief derived from bathymetry published by Cochrane and others (2022). *B*, Backscatter intensity shows false low-backscatter striping that the numerical analysis converts to soft bottom, as well as data processing backscatter normalization problems.

CMECS Polygons

A shapefile consisting of polygons around areas of unique combinations of raster variables was produced for the study area and is available in the companion data release (Cochrane and others, 2022). The shapefile is attributed with CMECS geoform, substrate, modifier, and biotic component values. Each component is represented in the shapefile by a CMECS code and a description from the CMEC standard (FGDC, 2012).

The modifier component is a direct translation of the raster attribute classes into the polygons. The modifier variable in the shapefile encodes CMECS induration, slope, and depth class. The induration is derived directly from the CMECS induration raster substrate modifier (soft, mixed, and hard). The slope is classified into CMECS slope classes that exist in this dataset: flat (0–5 degrees), sloping (5–30 degrees), and steeply sloping (30–60 degrees). The depth is classified into zones that exist in the dataset: circalittoral (30–200 m), mesobenthic (200–1,000 m), and bathybenthic (1,000–4,000 m). The mesobenthic zone was divided into five subregions for this study. Those divisions are included in the modifier description as numbers 1–5 (fig. 4). The CMECS codes come from a technical guidance document (Marine and Coastal Spatial Data Subcommittee, 2014). For example, a hard (sediment induration class 1), steeply sloping (slope class 3) area with depths ranging from 250 to 400 m (benthic depth zone 5) would have a modifier code of SI1S3BDZ5. Notice that the CMECS induration code scheme is the reverse of the seafloor character (SFC) coding used in previous studies, including the windfarm area off Oregon (Cochrane and others, 2017), where hard has a value of 3, mixed is 2, and soft is 1.

The geoform component elements were derived from a combination of BPI classes, slope classes, and the CMECS induration raster. The BPI raster was classified into concave, convex, and flat areas. Several geoforms were either too large or too subtle to delineate with BPI. These geoforms include banks, a sediment wave field, and a pockmark field. The pockmark field was populated by small pockmarks of about 10 m in radius. The study area was also populated with numerous larger pockmarks in deeper water, with radii of approximately 100 m that BPI was able to delineate individually. In pockmark areas near the boundary of two depth zones, some pockmarks are divided into separate polygons for each depth zone. Sediment slide deposit geoforms were delineated by hand aggregating the ridge, scarp, and other BPI-derived polygons that were located within the body of the deposit.

The substrate component is based on the Folk (1954) sediment grain-size classification scheme. For this study, the CMECS induration value for the polygons was converted manually into grain-size classes based on the geoform of the polygon and the most adjacent ground-truth substrate observations. Geologic inference was also used in the assignment of grain size for many polygons, and in this case, a less specific class was used, such as “coarse unconsolidated” rather than “cobble.”

Biotic group attributes were added to the CMECS polygon shapefile using the statistical associations of biota to physical habitat described by Kuhnz and others (2021). The CMECS biotic component is less well populated than the other components and does not have classes that match all the Kuhnz and others (2021) biotopes, resulting in duplicate CMECS codes and descriptions in the shapefile that are differentiated parenthetically (for example, B2.8.1(a) and B2.8.1(b); table 2). Biotope 9 was identified via video that was recorded outside the recent MBES mapped study area and in an area that was mapped at lower resolution than the data used for this study. The biotope 9 data were collected to advance the research effort to understand the structure and sediment dynamics for the larger region, but the biotope information could not be numerically associated with the attributes derived from the higher resolution data used for this study.

Table 2. Biotopes from Kuhnz and others (2021) and the related Coastal and Marine Ecological Classification Standard (CMECS) (Federal Geographic Data Committee [FGDC], 2012) descriptions of geoform, substrate, and biotic components for the offshore Morro Bay, California, study area.

[Biotopes are available as a polygon attribute in the companion data release (Cochrane and others, 2022). The CMECS biotic component is less well populated than the other components and does not have classes that match all the Kuhnz and others (2021) biotopes, resulting in duplicate CMECS codes (Marine and Coastal Spatial Data Subcommittee, 2014) and descriptions in the data release shapefile that are differentiated parenthetically, for example B2.8.1(a) and B2.8.1(b). Biotope 9 is outside of the study area and is not included in this table. Biotopes 12 and 13 could be distinguished by Kuhnz and others (2021) by statistically significant differences in species abundance and presence but could not be delineated by physical habitat variation. The predominant species in biotope 12 was *Cerianthid* sp. (anemones) whereas in biotope 13 it was *Sabellidae* (a burrowing polychaete worm). In the Cochrane and others (2022) shapefile, the two biotopes are identified as biotope 12, *Cerianthid/Sabellidae* on hard substrate. The mesobenthic zone was subdivided into five zones for this study. Those divisions are included in the modifier description as numbers 1–5 (fig. 4)]

Biotope	Geoform	Substrate type	Modifier	CMECS code	CMECS description
1	Apron	Mud	Soft flat mesobenthic 2	B3.27.1	Sea star on soft substrate
2	Pockmark	Mud	Soft flat mesobenthic 4	B3.8.1(a)	Cerianthid anemone in pockmark
3	Pockmark	Mud	Soft flat mesobenthic 5	B3.8.1(b)	Cerianthid anemone in pockmark
3	Pockmark	Mud	Soft flat mesobenthic 5	B3.8.1(b)	Cerianthid anemone in pockmark
4	Scarp	Muddy sand	Soft sloping mesobenthic 4	B3.8.1(c)	Cerianthid anemone on soft substrate
4	Bank-scarp	Muddy sand	Soft sloping mesobenthic 4	B3.8.1(c)	Cerianthid anemone on soft substrate
5	Scarp	Muddy sand	Soft sloping mesobenthic 3	B3(a)	Sea cucumber on soft substrate
5	Bank	Coarse unconsolidated	Mixed flat mesobenthic 3	B3(a)	Sea cucumber on soft substrate
6	Basin	Mud	Soft flat mesobenthic 5	B3.8.1(d)	Cerianthid anemone on soft substrate
7	Scarp	Coarse unconsolidated	Mixed sloping mesobenthic 2	B2.10	Brittle star on mixed substrate
7	Scarp	Rock	Hard sloping mesobenthic 2	B2.10	Brittle star on mixed substrate
7	Bank	Coarse unconsolidated	Mixed flat mesobenthic 2	B2.10	Brittle star on mixed substrate
7	Bank-ridge	Rock	Hard flat mesobenthic 2	B2.10	Brittle star on mixed substrate
8	Scarp	Rock	Hard steeply sloping mesobenthic 5	B2(a)	Caridea shrimp on hard substrate
8	Bank-scarp	Rock	Hard steeply sloping mesobenthic 5	B2(a)	Caridea shrimp on hard substrate
8	Bank-ridge	Rock	Hard steeply sloping mesobenthic 5	B2(a)	Caridea shrimp on hard substrate
10	Bank-scarp	Rock	Hard sloping mesobenthic 3	B2(b)	Galatheid crab on bedrock
10	Terrace	Rock	Hard flat mesobenthic 4	B2(b)	Galatheid crab on bedrock
10	Ridge	Rock	Hard flat mesobenthic 4	B2(b)	Galatheid crab on bedrock
10	Bank-scarp	Rock	Hard sloping mesobenthic 3	B2(b)	Galatheid crab on bedrock
10	Bank-ridge	Rock	Hard sloping mesobenthic 3	B2(b)	Galatheid crab on bedrock
10	Bank-terrace	Rock	Hard flat mesobenthic 4	B2(b)	Galatheid crab on bedrock
10	Bank-ridge	Rock	Hard flat mesobenthic 4	B2(b)	Galatheid crab on bedrock

Table 2. Biotopes from Kuhnz and others (2021) and the related Coastal and Marine Ecological Classification Standard (CMECS) (Federal Geographic Data Committee [FGDC], 2012) descriptions of geoform, substrate, and biotic components for the offshore Morro Bay, California, study area.—Continued

Biotope	Geoform	Substrate type	Modifier	CMECS code	CMECS description
11	Scarp	Coarse unconsolidated	Mixed sloping mesobenthic 3	B2.10.2	Brittle star on hard substrate
11	Bank-scarp	Coarse unconsolidated	Mixed sloping mesobenthic 3	B2.10.2	Brittle star on hard substrate
12 and 13	Bank-scarp	Coarse unconsolidated	Mixed sloping mesobenthic 4	B2(c)	Cerianthid/Sabellidae on hard substrate
12 and 13	Bank-scarp	Rock	Hard sloping mesobenthic 4	B2(c)	Cerianthid/Sabellidae on hard substrate
12 and 13	Bank-scarp	Coarse unconsolidated	Mixed sloping mesobenthic 4	B2(c)	Cerianthid/Sabellidae on hard substrate
12 and 13	Bank-scarp	Rock	Hard sloping mesobenthic 4	B2(c)	Cerianthid/Sabellidae on hard substrate
14	Basin	Mud	Soft flat bathybenthic	B3(b)	Anemone on soft sediment
14	Channel	Mud	Soft flat bathybenthic	B3(b)	Anemone on soft sediment
14	Bank	Mud	Soft flat bathybenthic	B3(b)	Anemone on soft sediment
15	Pockmark	Mud	Soft flat mesobenthic 3	B3.3	Sea pen in pockmark
16	Bank-channel	Sand	Mixed sloping mesobenthic 4	B2(d)	Caridea shrimp on soft sediment
17	Pockmark	Mud	Soft flat bathybenthic	B3.8.1(e)	Cerianthid anemone in pockmark
18	Basin	Mud	Soft flat mesobenthic 4	B3.8.1(f)	Cerianthid anemone on soft substrate

Results

The CMECS induration raster (fig. 6) shows the study area substrate is predominantly mud, which occupies 7,804 km^2 (92.7 percent) of the study area. Mixed substrate areas are found on and around rocky banks and on the shelf break; they comprise 404 km^2 (4.8 percent) of the study area. Hard substrate areas are found predominantly on the tops and edges of banks and on bank ridges that separate canyons incising the banks. Hard substrates comprise 211 km^2 of the study area (2.5 percent).

There are 297 unique combinations of variables resulting in 280,397 CMECS polygons in the study area. These polygons are grouped into 16 unique biotopes (table 2), 6 substrate types (table 3), 28 modifier groups (table 4), and 22 geoforms (table 5) (Cochrane and others, 2022). Sand substrate areas were assigned to soft induration or mixed induration class based on the CMECS induration numerical classification that used the backscatter intensity data.

The combinations of modifiers closely differentiate areas of different induration, slope, and depth. The subdivisions of the mesobenthic depth zone are removed for table 4 but are preserved in the polygon shapefile "Modifier Description" attribute in the accompanying data release (Cochrane and others, 2022). Adding the depth subdivisions results in 63 unique modifier combinations. The "soft steeply sloping" areas are likely artifacts of MBES noise that were not edited out of the rasters during the attempted manual editing effort. There are likely erroneous mixed and hard steeply sloping areas as well.

The physiographic setting of the study area is divided between continental shelf and continental slope settings. Three large rock bank features were manually delineated so that geoforms situated on rock banks were differentiated from those geoforms that were found elsewhere in the study area (table 5). Geoforms labelled as simply "Bank" are flat mud areas on the bank top. Rocky "Bank-ridge" features occupy 280.9 km^2 (3.3 percent) of the study area. The geoform of greatest area was the "Basin" geoform, which was differentiated based on slope (0–5 degrees), bathymetry class (>500 m), and muddy substrate. Figure 7 shows the spatial distribution of a subset of the geoforms discussed in this report.

Table 3. The six seafloor substrate types identified in the offshore Morro Bay, California, study area with their total areas of coverage.

[CMECS, Coastal and Marine Ecological Classification Standard; km^2, square kilometer]

CMECS code	Substrate types	Area (km^2)
S1.2.2.5	Mud	6,141.3
S1.2.2.3	Muddy sand	1,554.5
S1.2.2.2	Sand	152.2
S1.2.1	Coarse unconsolidated	271.2
S1.1	Rock	211.8
S1.2.2	Fine unconsolidated	92.9

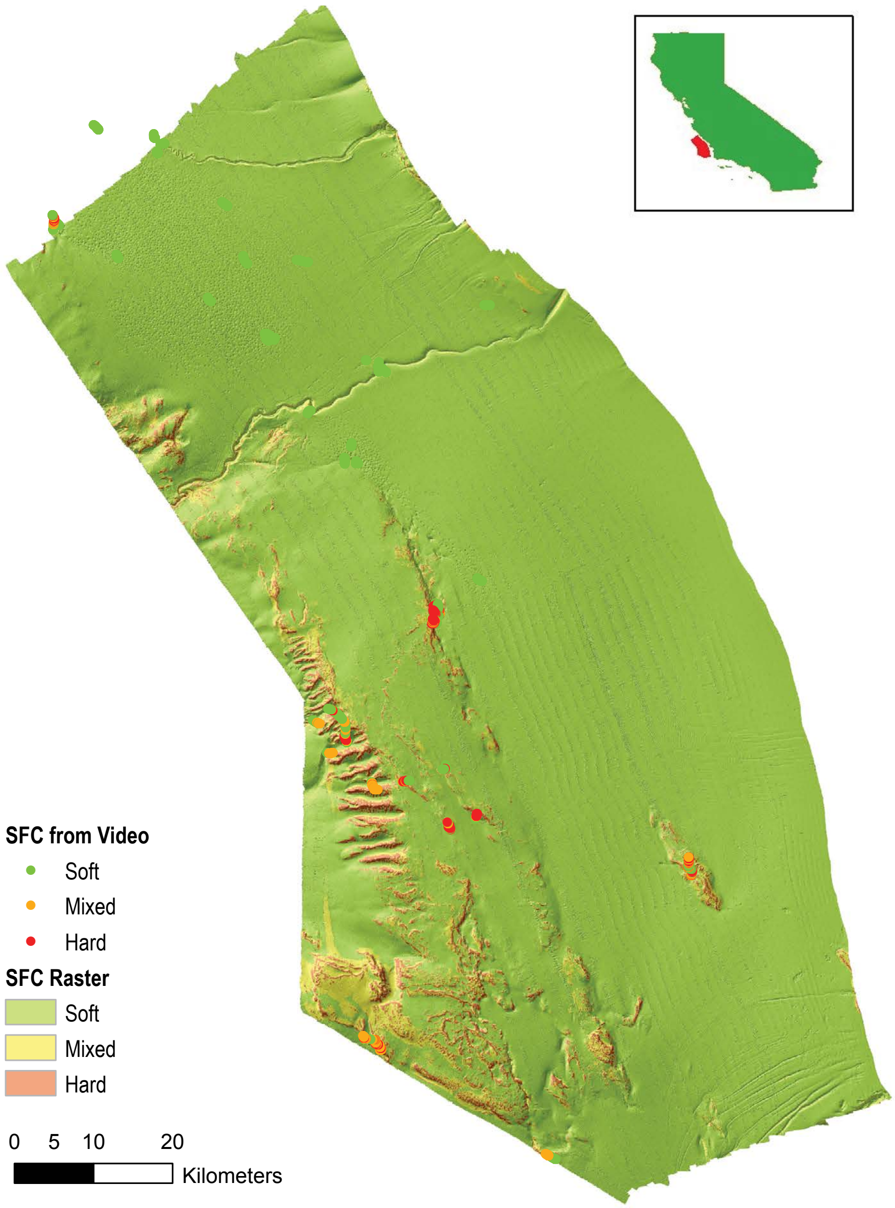


Figure 6. Map showing Coastal and Marine Ecological Classification Standard (CMECS) induration substrates raster image draped on the offshore Morro Bay, California, study area shaded relief. Video footage was analyzed by Monterey Bay Aquarium and Research Institute (MBARI) to catalog the substrate, terrain, and the assemblage of organisms that occupy the various areas (Kuhnz and others, 2021). The observations of physical habitat follow the method of Tissot and others (2006) and Greene and others (1999) but use point observations instead of lengths of transect. Points show the locations and substrate type of the video observations used in the video-supervised classification. The MBARI video observations are published as a point shapefile by Cochrane and others (2022). SFC, seafloor character. Shaded relief from bathymetry published by Cochrane and others (2022).

Table 4. The 28 combinations of Coastal and Marine Ecological Classification Standard (CMECS) modifiers identified in the offshore Morro Bay, California, study area with their total areas of coverage.

[km^2, square kilometer]

CMECS code	Modifier description	Area (km^2)
SI3S3BDZ6	Soft steeply sloping bathybenthic	0.10
SI3S3BDZ5	Soft steeply sloping mesobenthic	0.09
SI3S3BDZ4	Soft steeply sloping circalittoral	0.00
SI3S2BDZ6	Soft sloping bathybenthic	51.92
SI3S2BDZ5	Soft sloping mesobenthic	142.03
SI3S2BDZ4	Soft sloping circalittoral	3.06
SI3S1BDZ6	Soft flat bathybenthic	726.37
SI3S1BDZ5	Soft flat mesobenthic	6,678.16
SI3S1BDZ4	Soft flat circalittoral	201.24
SI2S3BDZ6	Mixed steeply sloping bathybenthic	0.22
SI2S3BDZ5	Mixed steeply sloping mesobenthic	0.30

Table 4. The 28 combinations of Coastal and Marine Ecological Classification Standard (CMECS) modifiers identified in the offshore Morro Bay, California, study area with their total areas of coverage.—Continued

CMECS code	Modifier description	Area (km^2)
SI2S3BDZ4	Mixed steeply sloping circalittoral	0.01
SI2S2BDZ6	Mixed sloping bathybenthic	32.58
SI2S2BDZ5	Mixed sloping mesobenthic	149.84
SI2S2BDZ4	Mixed sloping circalittoral	4.67
SI2S1BDZ6	Mixed flat bathybenthic	24.05
SI2S1BDZ5	Mixed flat mesobenthic	194.87
SI2S1BDZ4l	Mixed flat circalittoral	3.19
SI2S1BDZ4	Mixed flat circalittoral	0.78
SI1S3BDZ6	Hard steeply sloping bathybenthic	0.10
SI1S3BDZ5	Hard steeply sloping mesobenthic	0.26
SI1S3BDZ4	Hard steeply sloping circalittoral	0.00
SI1S2BDZ6	Hard sloping bathybenthic	11.22
SI1S2BDZ5	Hard sloping mesobenthic	91.60
SI1S2BDZ4	Hard sloping circalittoral	0.77
SI1S1BDZ6	Hard flat bathybenthic	8.48
SI1S1BDZ5	Hard flat mesobenthic	97.01
SI1S1BDZ4	Hard flat circalittoral	0.85

Table 5. Coastal and Marine Ecological Classification Standard (CMECS) geoforms identified in the offshore Morro Bay, California, study area with their total areas of coverage.

[Geoforms are available as a polygon attribute in the companion data release (Cochrane and others, 2022). km^2, square kilometer]

CMECS code	Physiographic setting	Geoform	Area (km^2)
Gt8p6g1.9	Shelf	Channel	8.855
Gt8p6g1.41	Shelf	Natural levee	0.026
Gt8p6g1.48	Shelf	Ridge	0.845
Gt8p6g1.54	Shelf	Scarp	4.951
Gt8p8g1.1	Slope	Apron	992.724
Gt8p8g1.2	Slope	Bank	1,452.543
Gt8p8g1.2g1.9	Slope	Bank-channel	296.205
Gt8p8g1.2g1.48	Slope	Bank-ridge	280.943
Gt8p8g1.2g1.54	Slope	Bank-scarp	64.345
Gt8p8g1.2g1.61	Slope	Bank-slope	29.272
Gt8p8g1.2g1.66	Slope	Bank-terrace	31.102
Gt8p8g1.4	Slope	Basin	3,715.147
Gt8p8g1.9	Slope	Channel	245.741
Gt8p8g1.41	Slope	Natural levee	97.772
Gt8p8g1.47	Slope	Pockmark	84.339
Gt8p8g1.46	Slope	Pockmark field	762.623
Gt8p8g1.48	Slope	Ridge	12.245
Gt8p8g1.54	Slope	Scarp	59.546
Gt8p8g1.53	Slope	Sediment wave field	92.904
Gt8p8g1.64	Slope	Submarine slide deposit	1.147
Gt8p8g1.66	Slope	Terrace	21.885
Gt8p6g1.66	Slope	Terrace	168.651

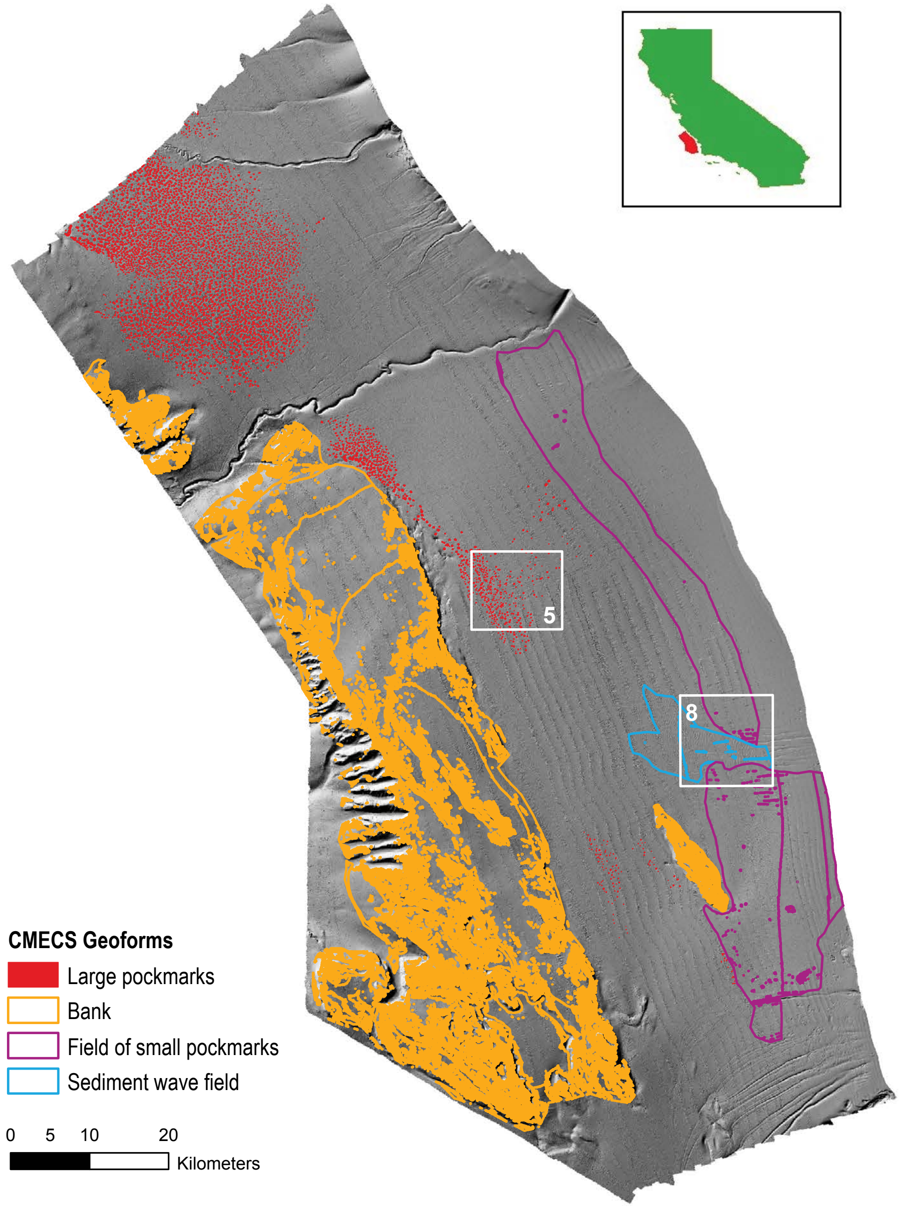


Figure 7. Map showing Coastal and Marine Ecological Classification Standard (CMECS) geoform boundaries in the offshore Morro Bay, California, study area. White boxes show the location of figure 5 and figure 8 images of the seafloor. Shaded relief derived from bathymetry published by Cochrane and others (2022).

Channels seen in the bathymetry were delineated into several geoforms owing to the changes in curvature of the seafloor related to them. Concave areas are assigned to the “Channel” geoform whereas convex areas were assigned to the “Natural Levee” geoform. In between are slopes with no curvature that were assigned to the “Scarp” geoform. Ground truth is lacking in channel areas that would help determine the biological significance of these channel geoform components, if any.

A sediment wave field and fields of small pockmarks were observed in the bathymetry shaded relief that were low in relief and lacked induration, which prevented them from being delineated numerically (fig. 8). The boundaries of these fields were hand drawn and would otherwise have been classified as “Basin” geoforms. These smaller pockmarks have radii of about 10 m whereas the pockmarks individually delineated here and described previously by Paull and others (2002) have radii of about 100 m. The sediment wave area bisects the areas of small pockmarks, suggesting that ocean bottom-current energy events that created the sediment waves post-date the formation of the pockmarks. The fields are broken by channel polygons with intermittent relief at the scale of detection in the numerical analysis.

Kuhnz and others (2021) identified a total of 18 biotopes in the study area (table 2). Of these, 16 were unique in terms of combinations of MBES-derived variables within the study area as explained in the “Methods” section of this report. Figure 9 shows the spatial extent of the biotopes derived by selection of polygons with comparable physical habitat attribute values as those observed in the video for the biotopes as shown in table 2. Characteristics of the water column (oxygen content, temperature, and salinity) and eight different biota assemblage statistics were measured during the dives and are discussed by Kuhnz and others (2021). Excluding biotope 9, areas covering 3,524 km^2 of seafloor were assigned into a biotope leaving 5,709 km^2 of seafloor unassigned in the study area. Some polygons are assigned to biotopes that are derived from ground-truth transects spatially distant from the polygons. Only two biotopes (biotopes 2 and 17; table 6) were observed on more than one ROV dive. Ground-truth ROV operations were significantly shortened in time by the sea state in the study area, limiting the number and distribution of video transects; additional video ground-truth information would improve the biotic results and increase confidence in their spatial distribution.

Several predictable general correlations between physical habitat and biota can be seen in the results. The number of species correlates to the substrate induration, rugosity, and slope (table 6) with more species found on greater slope and rugosity areas.

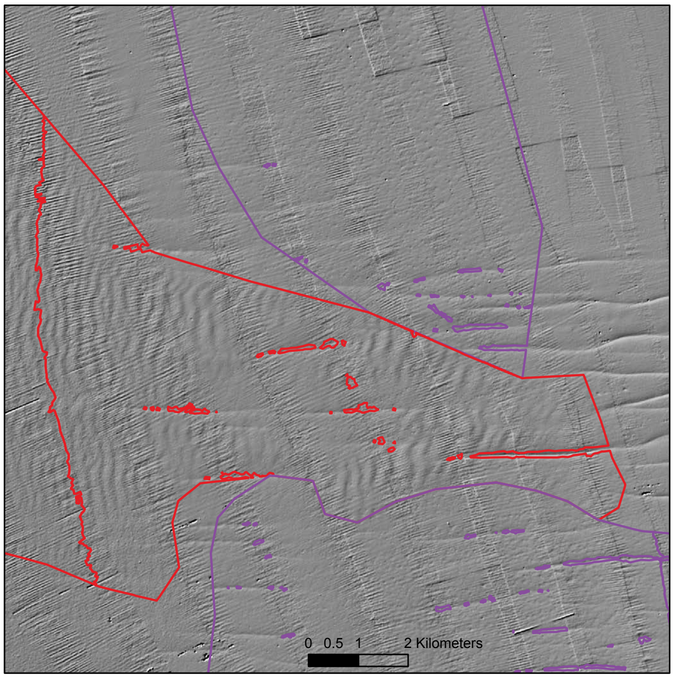


Figure 8. Image showing a portion of the offshore Morro Bay, California, study area shaded relief with geoform boundaries (see fig. 7 for location). Purple lines enclose the pockmark fields (or separate channel geoforms) and red lines enclose the sediment wave field (or separate channel geoforms). A sediment wave field and fields of small pockmarks were observed in the bathymetry shaded relief that were low in relief and lacked induration, which prevented them from being delineated numerically. The boundaries of these fields were hand drawn and would otherwise have been classified as "Basin" geoforms. These smaller pockmarks have radii of about 10 meters whereas the pockmarks individually delineated here and described previously in Paull and others (2002) have radii of about 100 meters. Geoform classifications from Coastal and Marine Ecological Classification Standard (CMECS). Shaded relief from bathymetry published by Cochrane and others (2022).

Table 6. Biotope attribute summary for the study area offshore Morro Bay, California.

[Biotopes from table 2. Biotope 9 is outside of the study area. m, depth to seafloor in meters; km^2, square kilometer]

Biotope	Dive	Mean no. species	Depth (m)	Slope (degrees)	Rugosity	Area (km^2)
1	U	10.5	301–500	0–5	Flat	1,194.40
2	B, F, T	16	701–900	0–5	Flat	14.26
3	R	14.3	>901	0–5	Flat	40.58
4	H	21.8	501–700	0–5	Flat	43.25
5	H	17.3	501–700	0–5	Flat	34.23
6	J	18.3	>901	0–5	Flat	489.20
7	Y	33	301–500	5–30	Rugose	62.78
8	S	35	>901	30–60	Rugose	0.01
10	K	41	501–700	5–30	Rugose	61.41
11	H	35	501–700	0–5	Rugose	25.41
12/13	H	45.7	701–900	5–30	Rugose	58.19
14	S	10.7	>901	0–5	Flat	661.51
15	G	25	501–700	0–5	Flat	4.86
16	K	15.7	701–900	0–5	Flat	0.17
17	A, V	14	>901	0–5	Flat	24.00
18	B	16.7	701–900	0–5	Flat	809.68

The spatial distribution (fig. 9) of the biotope groups is correlated to the depth zones used in the sampling design (fig. 4). Biotope 1, "Sea star on soft substrate" (table 2), was assigned to flat mud "Basin" geoform areas in the 301–500 m depth range. Biotope 1 was also assigned to the fields of small pockmarks in that depth zone despite there being no ground-truth observations of the small pockmarks or the biota associated with them. The assignment of the small-pockmark fields to biotope 1 was based on the lack of any other

We hypothesize that the primary reason for unassigned study areas is the lack of enough video observations of biotopes 12 and 13. Biotopes 12 and 13 could be distinguished by Kuhnz and others (2021) by statistically significant differences in species abundance and presence but could not be delineated by physical habitat variation. It was also not possible to distinguish them spatially because the transects they were observed on were on the same ROV dive (dive H; table 6). The predominant species in biotope 12 is *Cerianthid* species (sp.) (anemones), whereas in biotope 13 it is *Sabellidae* (a burrowing polychaete worm). In the CMECS shapefile, the biotope is identified as biotope 12, *Cerianthid/Sabellidae* on hard substrate. The other *Cerianthid* biotopes (2, 3, 4, 6, 17, 18) are similar in physical habitat and biota except that they are in different depth zones and some are in large pockmarks.

Though no large deepwater coral biotopes were identified in this study, a dive on E/V *Nautilus* expedition 123 did observe large specimens of several deepwater coral species on the southwestern flank of the Santa Lucia Bank (Raineault and others, 2021) (fig. 4). The observations of physical habitat from the E/V *Nautilus* expedition 123 dive H1831 are included in the video observation point shapefile in the data release that accompanies this study (Cochrane and others, 2022).

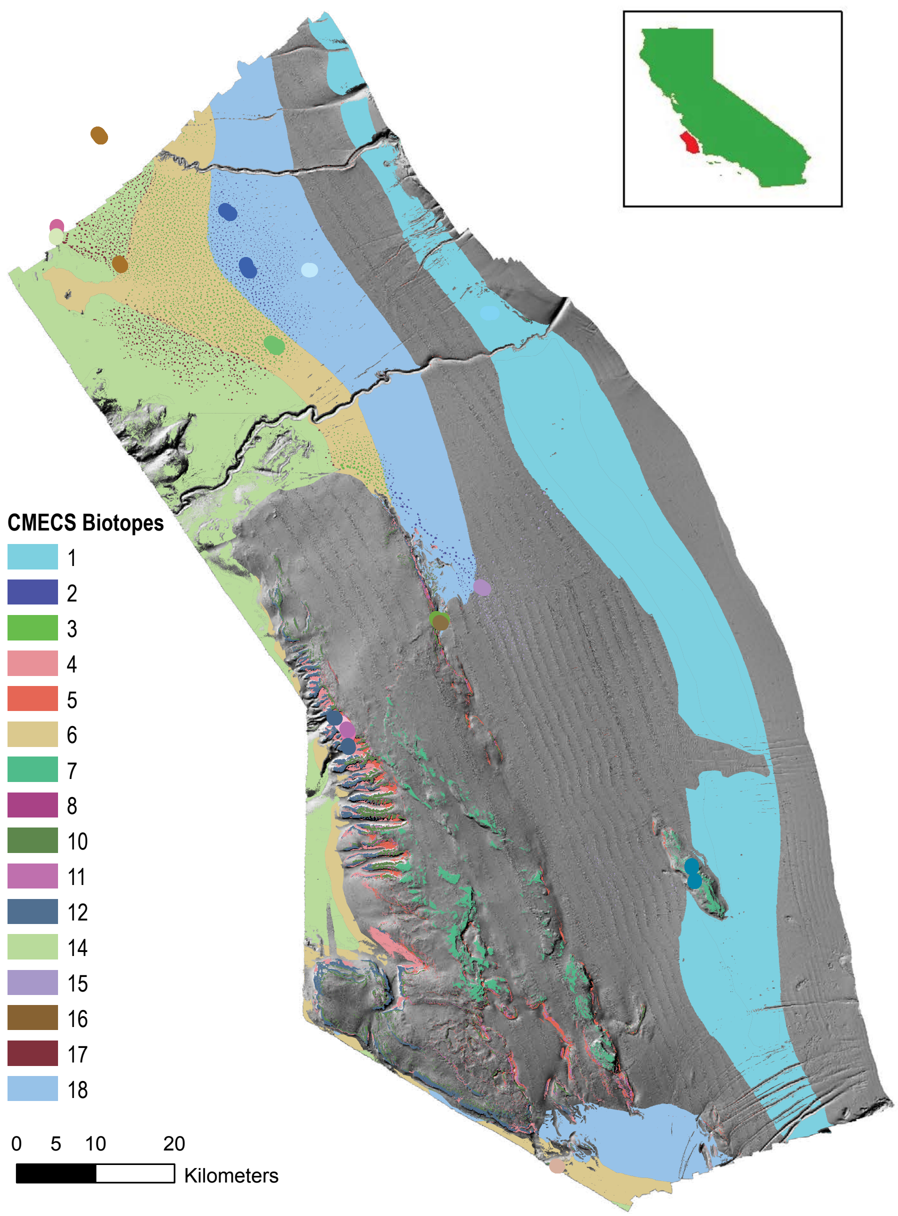


Figure 9. Map showing the distribution of unique communities called biotopes in the offshore Morro Bay, California, study area derived from invertebrate and fish community analyses (table 2) (Kuhnz and others, 2021). Biotope 9 is outside of the study area. The spatial distribution of the biotope groups is correlated to the depth zones used in the sampling design (fig. 4). Dots indicate the location of video observations associated with the biotopes. Video observations shown are from Monterey Bay Aquarium Research Institute (MBARI) transects only. Gray areas have combinations of physical attributes that do not match any biotope identified in the video (see table 6 for biotope definitions). CMECS, Coastal and Marine Ecological Classification Standard. Shaded relief from a 30-meter-resolution digital elevation model created by Monterey Bay Aquarium Research Institute.

Summary

Coastal and Marine Ecological Classification Standard (CMECS) geoform, substrate, and biotic component geographic information system (GIS) products were developed for the U.S. Exclusive Economic Zone of south-central California in the region of Santa Lucia Bank. The study area is in depths of 500 to 1,200 meters below the sea surface and adjacent to a decommissioned nuclear power plant with a developed electric grid connection, and in an area of high wind resource.

Data acquired for the study included multibeam echo sounder (MBES) data and remotely operated vehicle (ROV) video footage. The MBES mapping covered 8,424 square kilometers (km^2) and was accomplished on five separate surveys over a 4-year period from 2016 through 2019 on cooperative cruises carried out by the National Oceanic and Atmospheric Administration (NOAA) as part of the Expanding Pacific Research and Exploration of Submerged Systems (EXPRESS) collaboration (https://www.usgs.gov/centers/pcmsc/science/express-expanding-pacific-research-and-exploration-submerged-systems). The Scripps Institute of Oceanography surveyed a small portion of the area encompassing the Santa Lucia Bank Fault. MBES data collected for this study suffered from noise and signal loss during acquisition. Headings were north-northwest–south-southeast and the north-northwest tracks were facing almost directly into the swell. Large swell states caused noise by overwhelming the motion sensing system and by cavitation around the transducer. The noise creates false highs and lows in the bathymetry that the numerical analysis converts into areas of ruggedness and false low-backscatter stripes that the numerical analysis converts into soft bottom. The backscatter intensity also suffered from variation in values related to processing of the data and not related to genuine changes in seafloor induration. The individual backscatter raster images were manually reclassified to reduce discrepancies in overlying areas prior to mosaicking into a single raster. This was necessary so that the induration classification satisfied the video observation supervision. After the bathymetry and backscatter raster images were classified, a variety of filtering methods and manual editing were used to eliminate areas affected by noise artifacts.

Slope and fine scale bathymetric position index (BPI) derived from the bathymetry and the backscatter intensity were classified into the three CMECS induration classes using video-supervised maximum likelihood. The slope, BPI, and depth were then classified into CMECS classes and used with induration to delineate 297 unique combinations of variables, resulting in 280,397 CMECS polygons in the study area. These polygons are grouped into 16 unique biotopes, 6 substrate types, 28 modifier groups, and 22 geoforms. The study area substrate is predominantly soft sediment (mud and fine sand) covering 7,804 km^2 (92.7 percent) of the area. Mixed substrate (coarse sediment and low relief rock) areas are found on rocky banks, channel scarps, and the shelf break and comprise 404 km^2 (4.8 percent) of the study area. Hard substrate (boulder, megaclast, and bedrock) areas are found predominantly on the tops and edges of banks and on bank ridges that separate canyons incising the banks. Hard substrates comprise 211 km^2 of the study area (2.5 percent). The modifier groups encode the induration, slope, and depth class of the polygon.

Sixteen unique biotopes were delineated based on combinations of MBES data derived variables within the study area. In all, 3,524 km^2 of seafloor were assigned into biotopes, leaving 5,709 km^2 of seafloor in the study area unassigned. Some biotopes were assigned to separate areas spatially distant from the transects that defined the biotope. Only two biotopes, 2 and 17, were observed on more than one ROV dive. Anticipated relations between physical habitat and biota were observed in this study (for example, the number of species correlates with the substrate induration and rugosity). Slope is typically a predictive variable and was used in the classification of habitat, but the ground-truth data used for biotic component analysis included few steeply sloping areas. Ground-truth ROV operations were significantly shortened in time by the sea state in the study area; additional ground-truth data could improve the biotic results and increase confidence in their spatial distribution.

References Cited

Bureau of Ocean Energy Management [BOEM], 2018, Commercial leasing for wind power development on the Outer Continental Shelf (OCS) Offshore California (call for information and nominations): Federal Register, v. 83, no. 203, October 19, 2018, 83 FR 53096, p. 53096, accessed February 25, 2022, at https://thefederalregister.org/83-FR/53096.

Cochrane, G.R., 2008, Video-supervised classification of sonar data for mapping seafloor habitat, *in* Reynolds, J.R., and Greene, H.G., eds., Marine habitat mapping technology for Alaska: Fairbanks, University of Alaska, Alaska Sea Grant College Program, p. 185–194, https://doi.org/10.4027/mhmta.2008.13.

Cochrane, G.R., Hemery, L.G., and Henkel, S.K., 2017, Oregon OCS seafloor mapping—Selected lease blocks relevant to renewable energy: U.S. Geological Survey Open-File Report 2017–1045, and Bureau of Ocean Energy Management Outer Continental Shelf Study BOEM 2017–018, 51 p., accessed May 4, 2021, at https://doi.org/10.3133/ofr20171045.

Cochrane, G.R., Kuhnz, L.A., Gilbane, L., Dartnell, P. and Walton, M.A., 2022, Multibeam echo sounder, video observation, and derived benthic habitat data offshore of south-central California in support of the Bureau of Ocean Energy Management Cal DIG I, offshore alternative energy project: U.S. Geological Survey data release, https://doi.org/10.5066/P9QQZ27U.

Federal Geographic Data Committee [FGDC], 2012, Coastal and marine ecological classification standard: Federal Geographic Data Committee, Marine and Coastal Spatial Data Subcommittee, FGDC Document Number FGDC–STD–018–2012, accessed March 10, 2021, at https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf.

Folk, R.L., 1954, The distinction between grain size and mineral composition in sedimentary-rock nomenclature: The Journal of Geology v. 62, no. 4, 344–359, https://www.jstor.org/stable/30065016.

Greene, H.G., Yoklavich, M.M., Starr, R.M., O'Connell, V.M., Wakefield, W.W., Sullivan, D.E., McRea, J.E., and Cailliet G.M., 1999, A classification scheme for deep sea floor habitats, *in* Marine benthic habitats and their living resources—Monitoring, management and applications to Pacific Island countries: Oceanologica Acta Special Issue, v. 22, no. 6, p. 663–678, https://doi.org/10.1016/S0399-1784(00)88957-4.

Johnson, S.Y., Cochrane, G.R., Golden, N.E., Dartnell, P., Hartwell, S.R., Cochran, S.A., and Watt, J.T., 2017, The California seafloor and coastal mapping program—Providing science and geospatial data for California's State waters: Ocean and Coastal Management, v. 140, p. 88–104, accessed May 22, 2021, at https://doi.org/10.1016/j.ocecoaman.2017.02.004.

Kuhnz, L.A., Gilbane, L., Cochrane, G.R., and Paull, C.K., 2021, California deepwater investigations and groundtruthing (Cal DIG) I, Volume 1—Biological site characterization offshore Morro Bay, Camarillo (CA): Bureau of Ocean Energy Management Outer Continental Shelf (OCS) Study BOEM 2021–037, 67 p., accessed February 23, 2022, at https://espis.boem.gov/final%20reports/BOEM_2021-037.pdf.

Marine and Coastal Spatial Data Subcommittee, 2014, Coding system approach for coastal and marine ecological classification standard (CMECS) classification and modifier units: Federal Geographic Data Committee, Coastal and Marine Ecological Classification Standard Technical Guidance Document 2014–1, accessed May 2, 2021, at https://iocm.noaa.gov/standards/docs/cmecs-technical-guidance/CMECS-Coding-System-Approach-20140619-2.pdf.

McCulloch, D.S., 1987, Regional geology and hydrocarbon potential of offshore central California, chap. 16 *of* Scholl, D.W., Grantz, A., and Vedder, J.G., eds., Geology and resource potential of the continental margin of western North America and adjacent oceans—Beaufort Sea to Baja California: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6., p. 353–401, accessed February 25, 2022, at https://archives.datapages.com/data/circ_pac/0007/0353_f.htm.

Paull, C.K., Ussler, W., III, Maher, N., Greene, H.G., Rehder, G., Lorenson, T., and Lee, H., 2002, Pockmarks off Big Sur, California: Marine Geology, v. 181, no. 4, p. 325–335, https://doi.org/10.1016/S0025-3227(01)00247-X.

Raineault, N.A., Flanders, J., and Niiler, E., eds., 2021, New frontiers in ocean exploration—The E/V *Nautilus*, NOAA Ship *Okeanos Explorer*, and R/V *Falkor* 2020 field season: Oceanography supplement, v. 34, no. 1, 78 p., https://doi.org/10.5670/oceanog.2021.supplement.01.

Tissot, B.N., Yoklavich, M.M., Love, M.S., York, K., and Amend, M., 2006, Benthic invertebrates that form habitat on deep banks off southern California, with special reference to deep sea coral: National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service, Fishery Bulletin, v. 104, p. 167–18, accessed February 25, 2022, at https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/2006/1042/tissot.pdf.

Walton, M.A.L., Paull, C.K., Cochrane, G., Gilbane, L., Addison, J., Gwiazda, R., Kennedy, D., and Papesh, A., 2021, California Deepwater Investigations and Groundtruthing (Cal DIG) I, Volume 2—Fault and shallow geohazard analysis offshore Morro Bay: Bureau of Ocean Energy Management Outer Continental Shelf Study BOEM 2021–044, 47 p., accessed February 23, 2022, at https://espis.boem.gov/final%20reports/BOEM_2021-044.pdf.

Wright, D.J., Lundblad, E.R., Larkin, E.M., Rinehart, R.W., Murphy, J., Cary-Kothera, L., and Draganov, K., 2005, ArcGIS Benthic Terrain Modeler: National Oceanic and Atmospheric Administration Office for Coastal Management website, accessed February 23, 2022, at https://coast.noaa.gov/digitalcoast/tools/btm.html.

Moffett Field Publishing Service Center, California
Manuscript approved on March 29, 2022
Edited by Lisa Binder and Monica Erdman
Layout by Kimber Petersen

Cochrane and others—**Cal DIG I, V. 3—Benthic Habitat Characterization Offshore Morro Bay, California**—Open-File Report 2022–1035

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20221035