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California State Waters Map Series—Benthic Habitat Characterization in the Region Offshore Humboldt Bay, California

Open-File Report 2024–1047

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

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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)
mile, nautical (nmi)	1.852	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)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)

Datum

Latitude and longitude in this report are relative to the World Geodetic System of 1984 (WGS 84).

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
CDFW	California Department of Fish and Wildlife
CMECS	Coastal and Marine Ecological Classification Standard
COPC	California Ocean Protection Council
CSMP	California Seafloor Mapping Program
EEZ	Exclusive Economic Zone
FGDC	Federal Geographic Data Committee
GIS	geographic information system
MBES	multibeam echo sounder
MLC	maximum likelihood classification
MLPA	California Marine Life Protection Act
MHHW	Mean Higher High Water
NOAA	National Oceanic and Atmospheric Administration
POS-MV	position and orientation system for marine vessels
R/V	research vessel
SBET	smoothed best estimated trajectory
USGS	U.S. Geological Survey

California State Waters Map Series—Benthic Habitat Characterization in the Region Offshore Humboldt Bay, California

By Guy R. Cochrane

Abstract

Coastal and Marine Ecological Classification Standard (CMECS) geoform, substrate, and biotic component geographic information system (GIS) products were developed for the California State Waters of northern California in the region offshore of Humboldt Bay. The study was motivated by interest in development of offshore wind-energy capacity and infrastructure in Federal waters offshore. This project, carried out by the U.S. Geological Survey (USGS), resulted in four data releases for individual map blocks that are part of the "California State Waters Map Series": (1) Offshore of Arcata, (2) Offshore of Eureka, (3) Offshore of the Eel River, and (4) Offshore of Cape Mendocino. The study area consists of 436 square kilometers of multibeam echo sounder (MBES) data acquired by Fugro Pelagos, Inc., in 2007. Towed camera-sled video was acquired in 2009 and 2010 to supervise the classification of the MBES data into habitats, and single channel sparker data were collected to calculate sediment thickness above the transgressive unconformity. Using video observations of habitat as ground truth, derivatives of the MBES data were classified into 3 seafloor character types (hard-rugose, hard-flat, and soft-flat), 26 induration-slope-depth groups, and 15 geoforms. The study area substrate is predominantly soft-flat sediment (mud and fine sand) covering 73.6 percent of the area. Hard-flat substrate areas, predominantly coarse sediment in scour depressions, cover 5.4 percent of the study area. The hard-rugose substrate areas are primarily outcrops of layered sedimentary bedrock and constitute 20.9 percent of the study area. Fifteen geoforms were identified in the analysis. The predominant geoforms mirror the seafloor character results, shelf geoforms, rock outcrop geoforms, and scour depression geoforms. Rock and scour areas are restricted to the southern portion of the study area off Cape Mendocino where uplift has exposed bedrock. On the flat shelf area post-transgressive sediment varies in thickness from 1.7 meters (m) nearshore to 28.1 m offshore.

Introduction

Interest from private companies and State and Federal government agencies motivated this study to enable environmentally sound responses to the 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 for the study area offshore of Humboldt Bay, California. The California Energy Commission approved a $10.5 million grant in 2023 to transform the Port of Humboldt Bay into an offshore wind terminal that could support the development of 1.6 gigawatts (GW) of wind energy. The study area is adjacent to a developed electric grid connection, and in an area of high wind resource potential. BOEM is the lead agency responsible for planning and leasing in the U.S. Exclusive Economic Zone (EEZ) to assess baseline conditions of, and the potential effects on, the seafloor environment. The potential direct, indirect, and cumulative effects on the human, coastal, and marine environments are evaluated by BOEM to enable environmentally sound decisions about managing energy activities. Offshore wind development has the potential to affect the seafloor over large areas and thus BOEM has a fundamental need for seafloor mapping and habitat characterization. The information provided by this report and the accompanying data releases can enable a baseline assessment of the area's seafloor conditions and habitats, which is requisite for subsequent evaluations of the changes and impacts to the seafloor from offshore wind development operations. The U.S. Geological Survey (USGS) is mandated with providing Earth-science data acquisition and interpretation to provide information 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, 2018). The study area is in California State Waters adjacent to the decommissioned Humboldt Bay nuclear power plant, where there is a developed electric grid connection and in an area of high wind resource potential (fig. 1).

In 2007, the California Ocean Protection Council initiated the California Seafloor Mapping Program (CSMP), which was designed to create a comprehensive seafloor map of high-resolution bathymetry, marine benthic habitats, and geology within California's State Waters. The program supports many coastal-zone and ocean-management issues, including the California Marine Life Protection Act of 1999 (MLPA)

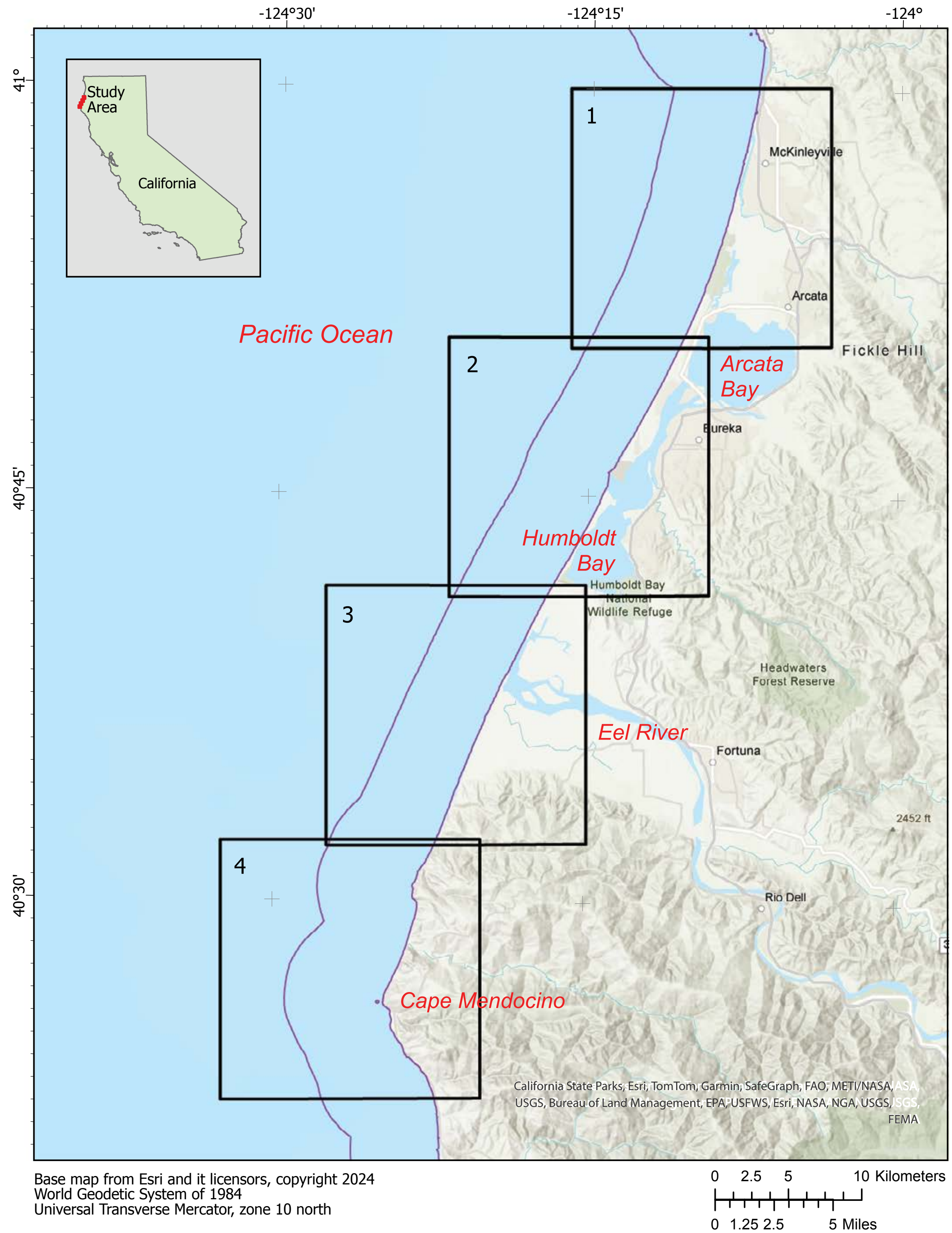

Figure 1. Map showing the four California Seafloor Mapping Program blocks in the study area offshore of Humboldt Bay, California: (1) Offshore of Arcata, (2) Offshore of Eureka, (3) Offshore of the Eel River, and (4) Offshore of Cape Mendocino. The map blocks are outlined in black, and the boundaries of California State Waters are outlined in purple.

(California Department of Fish and Wildlife [CDFW], 2008), which requires information about the distribution of ecosystems as part of the design and proposal process for the establishment of Marine Protected Areas. One focus of CSMP is to map California's State Waters with consistent methods at a consistent scale.

The CSMP approach is intended to create highly detailed seafloor maps through collection, integration, interpretation, and visualization of swath sonar bathymetric and backscatter data (either multibeam echosounder [MBES] or bathymetric sidescan sonar), seafloor video, seafloor photography, high-resolution seismic-reflection profiles, and bottom-sediment sampling data. The map products display seafloor morphology and character, identify marine benthic habitats, and illustrate both the surficial seafloor geology and shallow subsurface geology. It is emphasized that the habitat and geology models rely on the integration of multiple, high-resolution datasets and that ecosystems modeling would not be possible without such data.

This approach is based in part on recommendations of the Marine Mapping Planning Workshop (Kvitek and others, 2006), which was attended by coastal and marine managers and scientists from around the state. That workshop established geographic priorities for a coastal mapping project and identified the need for coverage of "lands" from the shore strand line (defined as Mean Higher High Water; MHHW) out to the limit of California's State Waters. Surveying the zone from MHHW out to 10-meter (m) water depth, however, is not consistently possible using ship-based surveying methods, owing to sea state (for example, waves, wind, or currents), kelp coverage, and shallow rock outcrops. Accordingly, some of the maps presented in this series do not cover the zone from the shore out to 5–10-m depth.

Data acquired for this study included MBES data (fig. 2), towed camera-sled video data, and single-channel sparker seismic data. The MBES mapping covered a total of 341 square kilometers (km^{2}) and was conducted by Fugro Pelagos, Inc., in 2008 as part of the California Seafloor Mapping Program (Johnson and others, 2017). Towed camera sled operations were carried out by USGS from 2008 to 2012.

This report discusses the methods used and the mapping and habitat characterization products produced by the USGS for the study area, including a seafloor character raster (Cochrane, 2008), a Coastal and Marine Ecological Classification Standard (CMECS) polygon shapefile map with geoform and biotic component attributes that follows the standards set by the Federal Geographic Data Committee (FGDC, 2012), and a model of sediment thickness above the transgressive unconformity. These mapping products are available from Cochrane (2023a, b, 2024a, b) so that they can be incorporated into geographic information system (GIS) and statistical analysis projects.

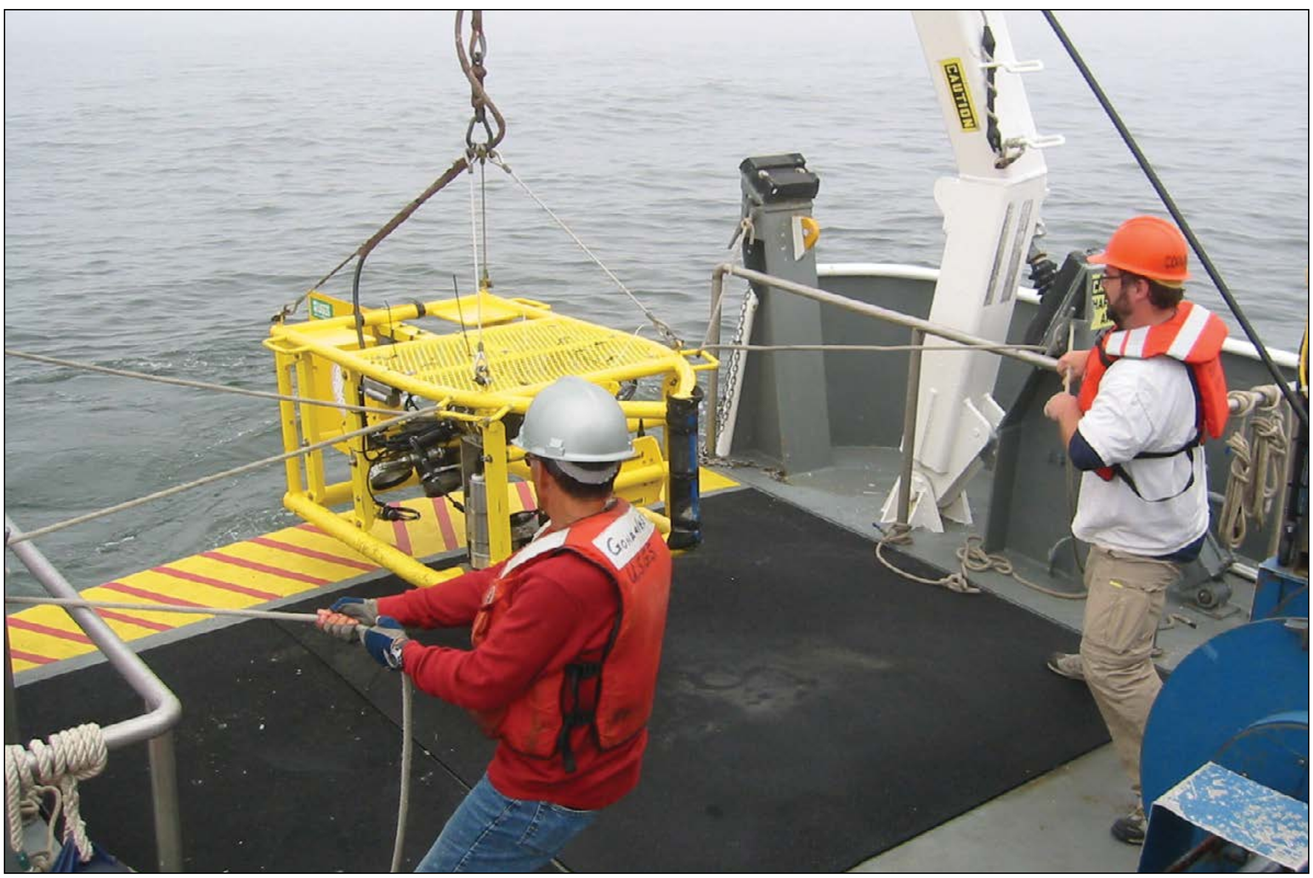

Figure 2. Photograph of camera sled being launched for ground-truth survey transect. Photograph by Guy R. Cochrane, 2009.

Purpose and Scope

The geographic scope of this study is focused on northern California State Waters in the region offshore of Humboldt Bay. 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. Cabling and other infrastructure to connect to the power grid, however, would necessarily pass through California State Waters. Previous high-resolution mapping in the study area was carried out by the California Seafloor Mapping Program (Johnson and others, 2017) on continental shelf areas; however, there had been no analysis of the data in this part of the continental shelf offshore of south-central California. The intent of this study is to inform and provide regional context for future site-specific surveys.

Methods

The methodological approach used to characterize the physical benthic habitat in the study area was used previously for the California Ocean Protection Council (COPC) funded project on the California continental shelf (Golden and Cochrane, 2013; Johnson and others, 2017). MBES bathymetry and backscatter data were acquired and used to design a seafloor video ground-truth survey. The USGS performed the acquisition of towed bottom-video camera and sparker seismic data using the Cal Poly Humboldt (formerly Humboldt State University) research vessel (R/V) Coral Sea. Physical habitat and biota were cataloged during the video survey and subsequently used to supervise the classification of the MBES data into physical habitat models. Single-channel sparker seismic data were acquired to model the thickness of sediment above the transgressive unconformity. 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) were acquired in the northern California region by Fugro Pelagos, Inc., in 2007, using a combination of 400-kilohertz (kHz) Reson 7125, 240-kHz Reson 8101, and 100-kHz Reson 8111 multibeam echosounders. During the Fugro Pelagos, Inc., mapping missions, an Applanix POS-MV (position and orientation system for marine vessels) was used to accurately position the vessels during data collection, and it also accounted for vessel motion such as heave, pitch, and roll, with navigational input from GPS receivers. Smoothed best estimated trajectory (SBET) files were postprocessed from logged POS-MV files. Sound-velocity profiles were collected with an Applied Microsystems (AM) SVPlus sound velocimeter. Soundings were corrected for (1) vessel motion using the Applanix POS-MV data, (2) variations in water-column sound velocity using the AM SVPlus data, and (3) variations in water height (tides) and heave using the postprocessed SBET data (California State University, 2016).

The backscatter-intensity data were postprocessed using Geocoder software. The backscatter intensities were radiometrically corrected (including despeckling and angle-varying gain adjustments), and the position of each acoustic sample was geometrically corrected for slant range on a line-by-line basis. After the lines were corrected, they were mosaicked into 0.5-m resolution images (California State University, 2016).

Within the final imagery, brighter tones indicate higher backscatter intensity, and darker tones indicate lower backscatter intensity. The intensity represents a complex interaction between the acoustic pulse and the seafloor, as well as characteristics within the shallow subsurface, providing a general indication of seafloor texture and composition. Backscatter intensity depends on numerous factors, including the acoustic source level, the frequency used to image the seafloor; the grazing angle, the composition and character of the seafloor, including grain size, water content, bulk density, and seafloor roughness; and some biological cover. Harder and rougher bottom types such as rocky outcrops or coarse sediment typically return stronger intensities (high backscatter, lighter tones), whereas softer bottom types such as fine sediment return weaker intensities (low backscatter, darker tones).

In 2023, the bathymetry and backscatter intensity mosaics were imported into an ArcGIS 10 GIS project, where they were mosaicked and clipped into single TIFF mosaics for data releases for each block (Cochrane, 2023a, b, 2024a, b).

Video Survey

To validate the interpretations of sonar data to turn it into geologically and biologically useful information, in 2012 the USGS towed a camera sled (fig. 2) over specific locations throughout the study area to collect video data to "ground truth" the seafloor. The camera sled was towed 1 to 2 m above the seafloor, at speeds of between 0.5 and 2.0 nautical miles/hour (nmi/hr). Ground-truth surveys in this map area include 9.72 trackline kilometers (km) of video along which 934 recorded seafloor observations of abiotic and biotic attributes. A visual estimate of slope was also recorded.

During the ground-truth survey cruises, the USGS camera sled housed two standard-definition (640×480-pixel resolution) video cameras (one forward looking, and one downward looking), as well as a high-definition (1,080×1,920-pixel resolution) video camera and an 8-megapixel digital still camera. Paired lasers were used to scale seafloor features.

The camera-sled tracklines (shown by colored dots on fig. 3) are sited to visually inspect areas representative of the full range of bottom hardness and rugosity in the map area. The video was fed in real time to the research vessel, where USGS and National Oceanic and Atmospheric Administration (NOAA) scientists recorded the geologic and biologic character of the seafloor, respectively. While the camera-sled was deployed, several different observations were recorded for a 10-second period once every minute, using the protocol of Anderson and others (2007). Observations of primary

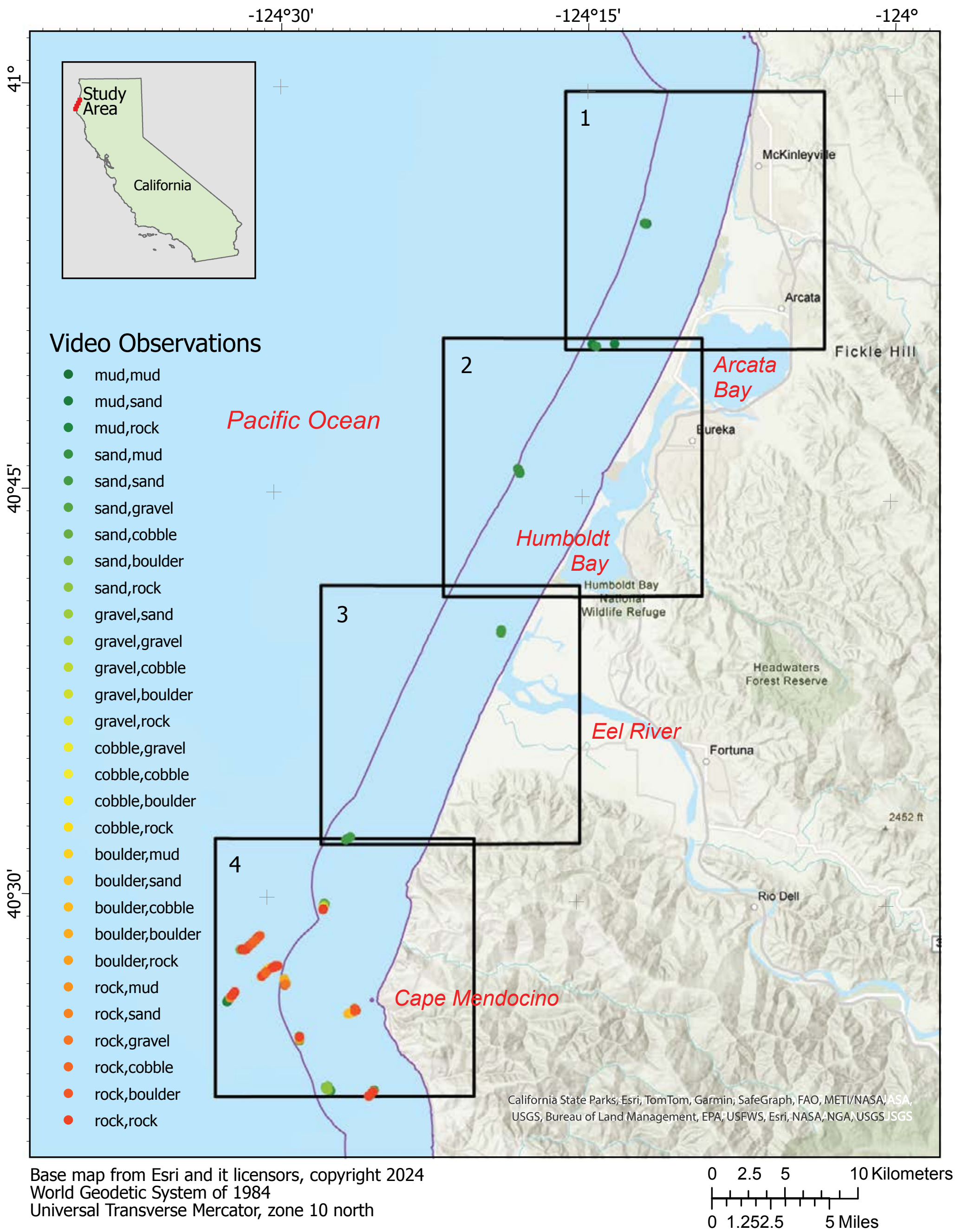

Figure 3. Map showing locations of video observations of substrate and other attributes used for analysis for this study, in the region offshore of Humboldt Bay, California. The four California Seafloor Mapping Program blocks in the study area are: (1) Offshore of Arcata, (2) Offshore of Eureka, (3) Offshore of the Eel River, and (4) Offshore of Cape Mendocino. The map blocks are outlined in black, and the boundaries of California State Waters are outlined in purple.

substrate, secondary substrate, slope, abiotic complexity, biotic complexity, and biotic cover were mandatory for every observation. Observations of key geologic features and the presence of key species were also recorded when observed.

Primary and secondary substrate, by definition, constitute greater than 50 and 20 percent of the seafloor, respectively, during an observation. The grain-size values that differentiate the substrate classes are based on the Wentworth (1922) scale, and the sand, cobble, and boulder sizes are classified as in Wentworth (1922). However, the difficulty in distinguishing the finest divisions in the Wentworth (1922) scale during video observations made it necessary to aggregate some grain-size classes, as was done in the Anderson and others (2007) methodology: the granule and pebble sizes have been grouped together into a class called “gravel,” and the clay and silt sizes have been grouped together into a class called “mud.” In addition, hard bottom and clasts larger than boulder size are classified as “rock.” Benthic-habitat complexity, which is divided into abiotic (geologic) and biotic (biologic) components, refers to the visual classification of local geologic features and biota that potentially can provide refuge for both juvenile and adult forms of various species (Tissot and others, 2006). The video was acquired from USGS field activities C-01-09-NC (https://cmgds.marine.usgs.gov/fan_info.php?fan=C109NC), and C-02-10-NC (https://cmgds.marine.usgs.gov/fan_info.php?fan=C210NC) and the observations are published as a point shapefile (Golden and Cochrane, 2013). The video and still photos can be viewed on the IOOS Coastal and Marine Geology Program video and photograph portal (Golden and others, 2015) by selecting the California Seafloor Mapping Program Imagery dataset available on the portal.

Substrate observations were translated into seafloor character 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. The substrate model is intended for use in developing species and biotope distribution models using the associations developed between biota and the physical habitat attributes.

Table 1. Humboldt Bay, California, State Waters region study area video observation combinations and the seafloor character value assigned to the seafloor.

[For the map showing seafloor character raster image, see figure 4. The induration is derived from the seafloor character raster class (National Oceanic and Atmospheric Administration [NOAA], 2014). 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 (>) 20 percent and less than (<) 50 percent. Substrate grain-size categories are based on those of Wentworth (1922). Granule and pebble sizes have been grouped together into a class called “gravel,” and the clay and silt sizes have been grouped together into a class called “mud.” In addition, hard bottom and clasts larger than boulder size are classified as “rock.” For abiotic complexity see (Tissot and others, 2006). Count is the number of observations of the combination of the other three values.]

Induration class	Primary substrate	Secondary substrate	Abiotic complexity	Count
Hard	Rock	Rock	High	16
Hard	Rock	Boulder	High	1
Hard	Rock	Sand	High	3
Hard	Boulder	Rock	High	1
Hard	Cobble	Rock	Moderate	1
Hard	Cobble	Boulder	Moderate	4
Hard	Rock	Sand	Moderate	5
Hard	Rock	Rock	Moderate	32
Hard	Rock	Boulder	Moderate	6
Hard	Boulder	Cobble	Moderate	19
Hard	Rock	Cobble	Moderate	1
Hard	Boulder	Rock	Moderate	4
Hard	Boulder	Boulder	Moderate	1
Hard	Mud	Rock	Moderate	4
Hard	Rock	Mud	Moderate	3
Hard	Boulder	Mud	Moderate	1
Hard	Boulder	Sand	Moderate	2
Mixed	Sand	Gravel	Low	11
Mixed	Sand	Rock	Low	7
Mixed	Gravel	Sand	Low	12
Mixed	Gravel	Gravel	Low	8
Mixed	Gravel	Cobble	Low	5
Mixed	Cobble	Gravel	Low	4
Mixed	Sand	Cobble	Low	1
Mixed	Rock	Rock	Low	37
Mixed	Cobble	Boulder	Low	1
Mixed	Cobble	Rock	Low	1
Mixed	Rock	Cobble	Low	2
Mixed	Gravel	Rock	Low	2
Mixed	Cobble	Cobble	Low	1
Mixed	Boulder	Cobble	Low	1
Mixed	Gravel	Boulder	Low	1
Mixed	Rock	Gravel	Low	1
Mixed	Mud	Rock	Low	4
Mixed	Rock	Mud	Low	9
Mixed	Gravel	Rock	Moderate	1
Mixed	Cobble	Gravel	Moderate	1
Mixed	Sand	Boulder	Moderate	6
Mixed	Sand	Rock	Moderate	5
Mixed	Sand	Gravel	Moderate	1
Mixed	Gravel	Boulder	Moderate	2
Soft	Sand	Mud	Low	29
Soft	Mud	Sand	Low	33
Soft	Sand	Sand	Low	84
Soft	Mud	Mud	Low	9

Seafloor Character Classification

The California State MLPA calls for protecting representative types of habitats in different depth zones and environmental conditions. A science team, assembled under the auspices of the CDFW, identified seven substrate-defined seafloor habitats in California's State Waters that can be classified using sonar data and seafloor video and photography. These habitats include rocky banks, intertidal zones, sandy or soft ocean bottoms, underwater pinnacles, kelp forests, submarine canyons, and seagrass beds (Section 2856-A-2, California Department of Fish and Wildlife, 2008). The following five depth zones, which determine changes in species composition, have been identified: Depth Zone 1, intertidal; Depth Zone 2, >intertidal to <30 m; Depth Zone 3, 30 to <100 m; Depth Zone 4, 100 to <200 m; and Depth Zone 5, deeper than 200 m (CDFW, 2008). The CDFW habitats can be considered a subset of the broader CMECS classification scheme.

A 2007 Coastal Map Development Workshop, hosted by the USGS in Menlo Park, California (Kvitek and others, 2006), identified the need for more detailed (relative to CMECS or Greene and others [1999] attributes) raster products that preserve some of the transitional character of the seafloor when substrates are mixed and (or) they change gradationally. The seafloor-character map, which delineates a subset of the CDFW habitats, is a GIS-derived raster product that can be produced in a consistent manner from data of variable quality covering large geographic regions. The seafloor character 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) hard-flat (coarse sand, gravel, cobble, and low relief rock outcrop), and (3) hard-rugged (boulder, megaclast, and rugged rock outcrop). The seafloor character classification was produced using video-supervised maximum likelihood classification (MLC) of the bathymetry and backscatter intensity from the MBES survey, following the method described by Cochrane (2008). For each survey, an MLC was run using the backscatter and vector ruggedness measurement (VRM). The VRM calculation was performed using the Terrain Ruggedness tool within the Benthic Terrain Modeler toolset v. 3.0 (Wright and others, 2012; available at http://esriurl.com/5754). The ground-truth video observation points informed the design of this polygon supervision shapefile. The polygon training sites were selected based on the ground truth video observations in low-noise MBES areas, where applicable, or otherwise they were selected using best judgement. MLC outputs were iterated, and training sites modified until an acceptable accuracy was achieved. Accuracies are based on an agreement between the predicted class where there is a video observation of the substrate of 80 percent or higher. Accuracies are reported in the four data releases associated with this area (Cochrane, 2023a, b, 2024a, b)

Noise in the bathymetry data was classified as areas of false highs and lows that the MLC numerical analysis converts into areas of ruggedness. The backscatter intensity shows false high- low-backscatter stripes that the numerical analysis converts into stripes in the classified raster. Hand editing in ArcGIS Pro was also done to remove noise artifacts and a majority filter was used to eliminate any remaining small areas of less than three pixels.

Coastal and Marine Ecological Classification Standard (CMECS) Polygons

Shapefiles consisting of polygons around areas of unique combinations of raster variables were produced for each block in the study area and is also available in the companion data releases (Cochrane, 2023a, b, 2024a, b). The shapefiles are attributed with CMECS geoform, substrate, and modifier component values. Each component is represented in the shapefile by a CMECS code and a description from the CMECS standard (FGDC, 2012).

The modifier component is a direct translation of the seafloor character raster classes, and derivatives of the bathymetry raster into the polygons; the modifier variable in the shapefile encodes CMECS induration, slope, and depth class. The induration is derived from the seafloor character raster class. Note that the CMECS induration code scheme (where hard has a value of 3, mixed is 2, and soft is 1) is the reverse of the seafloor character coding. The slope is classified into CMECS slope classes that exist in this dataset: flat (0–<5 degrees [°]), sloping (5–<30°), and steeply sloping (30–<60°). The depth is classified into zones that exist in the dataset: shallow infralittoral (0–5 m), deep infralittoral (5–<30), circalittoral (30–<200 m), and mesobenthic (200–<1,000 m). The CMECS modifier codes from the technical guidance document (NOAA, 2014) have been combined into a single attribute in the dataset. For example, a hard (sediment induration class 1), steeply sloping (slope class 3) area with depths ranging from 5–30 m (benthic depth zone 3) would have a modifier code of SI1S3BDZ3.

The geoform component polygon attribute values were derived from a combination of bathymetric position index (BPI), slope, and induration classes (table 2). The BPI raster was classified into concave, convex, and flat areas. Depth zone values were also used to distinguish submarine canyons from channels. Jetties and pipeline areas offshore of Eureka (not shown in table 2) were initially classified as rock outcrops and were manually re-attributed.

Table 2. Geoform classification attribute values for the Humboldt Bay, California, State Waters study area.

[The substrate induration is derived from the seafloor character raster class. The slope is classified into Coastal and Marine Ecological Classification Standard (National Oceanic and Atmospheric Administration [NOAA], 2014) slope classes: flat, 0–<5 degrees (°); sloping, 5–<30°; steeply sloping, 30–<60°. Depth zone: deep infralittoral, 5–<30 m; circalittoral, 30–<200 m; mesobenthic, 200–<1,000 m. Depth zone values were also used to distinguish submarine canyons from channels. The bathymetric position index (BPI) raster was classified into concave, convex, and flat areas. The geoform component polygon attribute values were derived from a combination of BPI, slope, and induration classes.]

Substrate induration	Slope	BPI	Depth zone	Geoform
Hard	Flat	Concave	Circalittoral	Channel
Hard	Sloping	Concave	Circalittoral	Channel
Hard	Steeply sloping	Concave	Circalittoral	Channel
Soft	Flat	Concave	Deep infralittoral	Depression
Soft	Sloping	Concave	Deep infralittoral	Depression
Hard	Sloping	Convex	Mesobenthic	Ridge
Hard	Steeply sloping	Convex	Mesobenthic	Ridge
Mixed	Flat	Convex	Deep infralittoral	Ridge
Mixed	Sloping	Convex	Deep infralittoral	Ridge
Soft	Flat	Convex	Deep infralittoral	Ridge
Soft	Sloping	Convex	Deep infralittoral	Ridge
Hard	Flat	Convex	Deep infralittoral	Rock outcrop
Hard	Flat	Flat	Deep infralittoral	Rock outcrop
Hard	Sloping	Flat	Deep infralittoral	Rock outcrop
Hard	Sloping	Convex	Deep infralittoral	Rock outcrop
Hard	Steeply sloping	Convex	Deep infralittoral	Rock outcrop
Hard	Steeply sloping	Flat	Deep infralittoral	Rock outcrop
Mixed	Flat	Flat	Circalittoral	Scour depression
Mixed	Sloping	Flat	Deep infralittoral	Scour depression
Mixed	Flat	Concave	Deep infralittoral	Scour depression
Mixed	Sloping	Concave	Deep infralittoral	Scour depression
Mixed	Flat	Flat	Circalittoral	Shelf
Soft	Flat	Flat	Deep infralittoral	Shelf
Soft	Sloping	Flat	Circalittoral	Shelf
Soft	Flat	Convex	Circalittoral	Shelf
Soft	Sloping	Convex	Circalittoral	Shelf
Mixed	Sloping	Flat	Deep infralittoral	Slope
Soft	Sloping	Flat	Mesobenthic	Slope
Soft	Sloping	Convex	Mesobenthic	Slope
Hard	Steeply sloping	Concave	Mesobenthic	Slump scar
Mixed	Steeply sloping	Concave	Circalittoral	Slump scar
Soft	Steeply sloping	Concave	Mesobenthic	Slump scar
Hard	Sloping	Concave	Mesobenthic	Submarine canyon
Hard	Flat	Concave	Mesobenthic	Submarine canyon
Mixed	Sloping	Concave	Mesobenthic	Submarine canyon
Mixed	Flat	Concave	Mesobenthic	Submarine canyon
Soft	Flat	Concave	Mesobenthic	Submarine canyon
Soft	Sloping	Concave	Mesobenthic	Submarine canyon

Results

The seafloor character raster (fig. 4) shows that the study area substrate is predominantly soft-flat, which is interpreted as mud and fine-grained sand and occupies 321.1 km^2 (73.6 percent) of the study area, predominantly in the area north of Cape Mendocino. Hard-flat substrate areas around rocky outcrops and the adjacent shelf are interpreted to be areas of coarse sediment formed by bottom current scour; they make up 23.5 km^2 (5.4 percent) of the study area. Hard-rugged substrates are interpreted to be bedrock outcrops and make up 91.4 km^2 of the study area (20.9 percent).

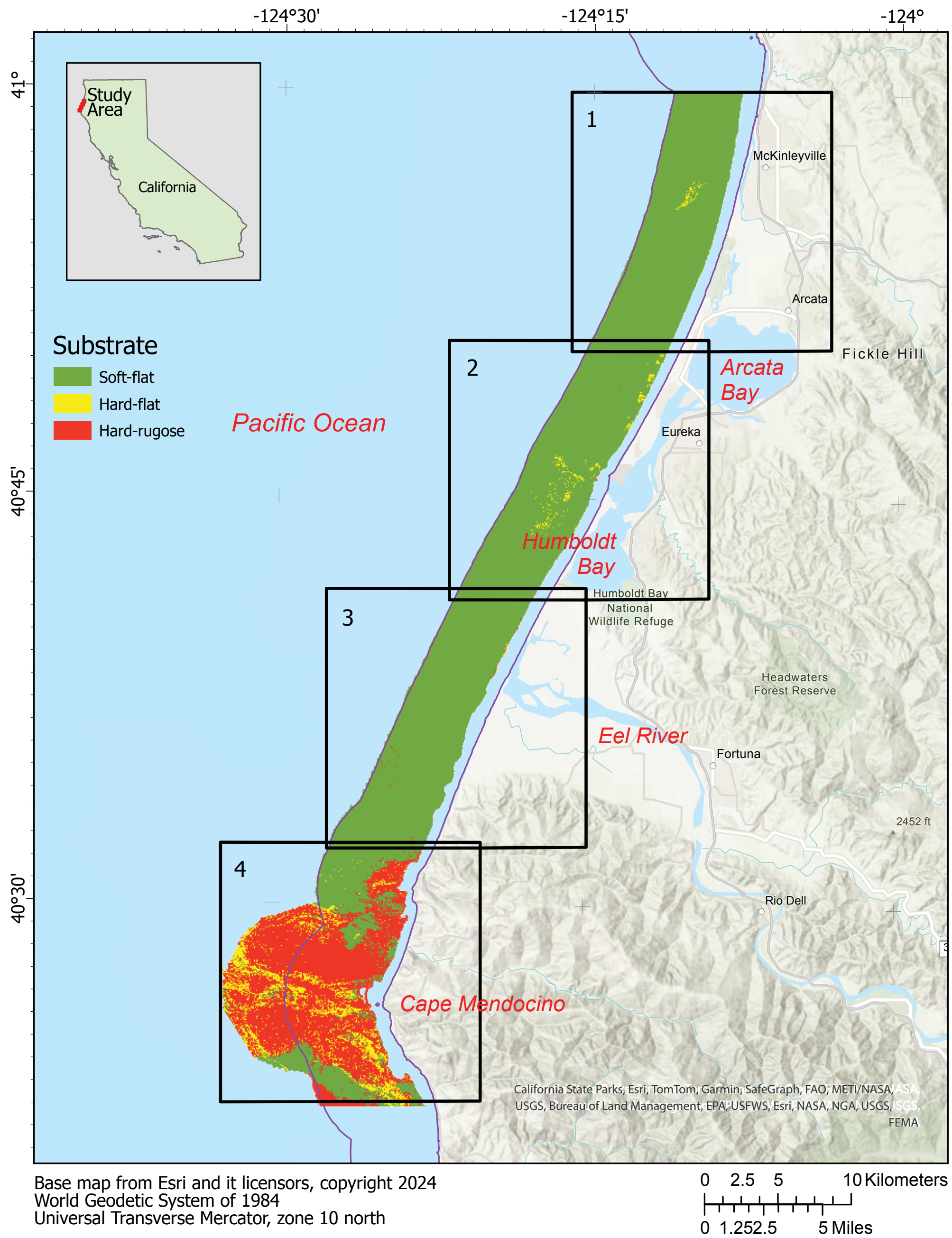

Figure 4. Map showing seafloor character raster image for the Humboldt Bay, California, study area. Using video observations of habitat as ground truth, derivatives of the multibeam echo sounder data were classified into three seafloor character types: hard-rugose, hard-flat, and soft-flat. Soft-flat is interpreted as mud and fine-grained sand. Hard-flat substrate areas around rocky outcrops and the adjacent shelf are interpreted to be areas of coarse sediment formed by bottom current scour. Hard-rugged substrates are interpreted to be bedrock outcrops. The four California Seafloor Mapping Program blocks in the study area are: (1) Offshore of Arcata, (2) Offshore of Eureka, (3) Offshore of the Eel River, and (4) Offshore of Cape Mendocino. The map blocks are outlined in red, and the boundaries of the California State Waters are outlined in purple.

The CMECS tectonic and physiographic settings of the study area are convergent continental margin and continental shelf north of Cape Mendocino. The Cape Mendocino area contains a triple junction (where the Gorda, North American, and Pacific Plates meet) with a strike-slip tectonic margin in the south (San Andreas Fault). There are 80 unique combinations of variables resulting in 371,115 CMECS polygons in the study area. These polygons are grouped into 26 modifier groups (table 3), and 15 geoforms (fig. 5, table 4). The combinations of modifiers differentiate areas of different induration, slope, and depth. Sand substrate areas were assigned to soft-flat induration or hard-flat induration

Table 3. The 26 combinations of Coastal and Marine Ecological Classification Standard (CMECS) modifiers identified in the Humboldt Bay, California, study area with their total areas of coverage.

[The Coastal and Marine Ecological Classification Standard (CMECS) codes from a technical guidance document (National Oceanic and Atmospheric Administration [NOAA], 2014). For example, a hard (sediment induration class 1), steeply sloping (slope class 3) area with depths ranging from 5–30 meter (m) (benthic depth zone 3) would have a modifier code of SI1S3BDZ3. Depth is classified into zones that exist in the dataset: shallow infralittoral (0–5 m), deep infralittoral (5–30 m), and circalittoral (30–200 m). Seafloor character types: hard-rugose, hard-flat, and soft-flat. m^2, square meter]

Modifier	Description	Area (m^2)	Percent
SI1S1BDZ1	Hard flat bottom at shallow infralittoral depth	8	0.000002
SI1S1BDZ3	Hard flat bottom at deep infralittoral depth	18,095,880	4.150381
SI1S1BDZ4	Hard flat bottom at circalittoral depth	34,614,068	7.938911
SI1S1BDZ5	Hard flat bottom at mesobenthic depth	364	0.000083
SI1S2BDZ2	Hard sloping bottom at shallow infralittoral depth	336	0.000077
SI1S2BDZ3	Hard sloping bottom at deep infralittoral depth	10,256,260	2.352325
SI1S2BDZ4	Hard sloping bottom at circalittoral depth	27,579,520	6.325502
SI1S2BDZ5	Hard sloping bottom at mesobenthic depth	981,695.6	0.225157
SI1S3BDZ2	Hard steeply sloping bottom at shallow infralittoral depth	324	0.000074
SI1S3BDZ3	Hard steeply sloping bottom at deep infralittoral depth	163,364	0.037468
SI1S3BDZ4	Hard steeply sloping bottom at circalittoral depth	122,240	0.028036
SI1S3BDZ5	Hard steeply sloping bottom at mesobenthic depth	84,360.786	0.019349
SI2S1BDZ3	Mixed flat bottom at deep infralittoral depth	5897,043.8	1.352517
SI2S1BDZ4	Mixed flat bottom at circalittoral depth	17,391,840	3.988906
SI2S1BDZ5	Mixed flat bottom at mesobenthic depth	76	0.000017
SI2S2BDZ3	Mixed sloping bottom at deep infralittoral depth	21,348	0.004896
SI2S2BDZ4	Mixed sloping bottom at circalittoral depth	60,980	0.013986
SI2S2BDZ5	Mixed sloping bottom at mesobenthic depth	548	0.000126
SI2S3BDZ4	Mixed steeply sloping bottom at circalittoral depth	4	0.000001
SI3S1BDZ3	Soft flat bottom at deep infralittoral depth	174,963,058	40.128658
SI3S1BDZ4	Soft flat bottom at circalittoral depth	145,325,042	33.33103
SI3S1BDZ5	Soft flat bottom at mesobenthic depth	496	0.000114
SI3S2BDZ3	Soft sloping bottom at deep infralittoral depth	9,812	0.00225
SI3S2BDZ4	Soft sloping bottom at circalittoral depth	436,100	0.100022
SI3S2BDZ5	Soft sloping bottom at mesobenthic depth	480	0.00011
SI3S3BDZ5	Soft steeply sloping bottom at mesobenthic depth	8	0.000002

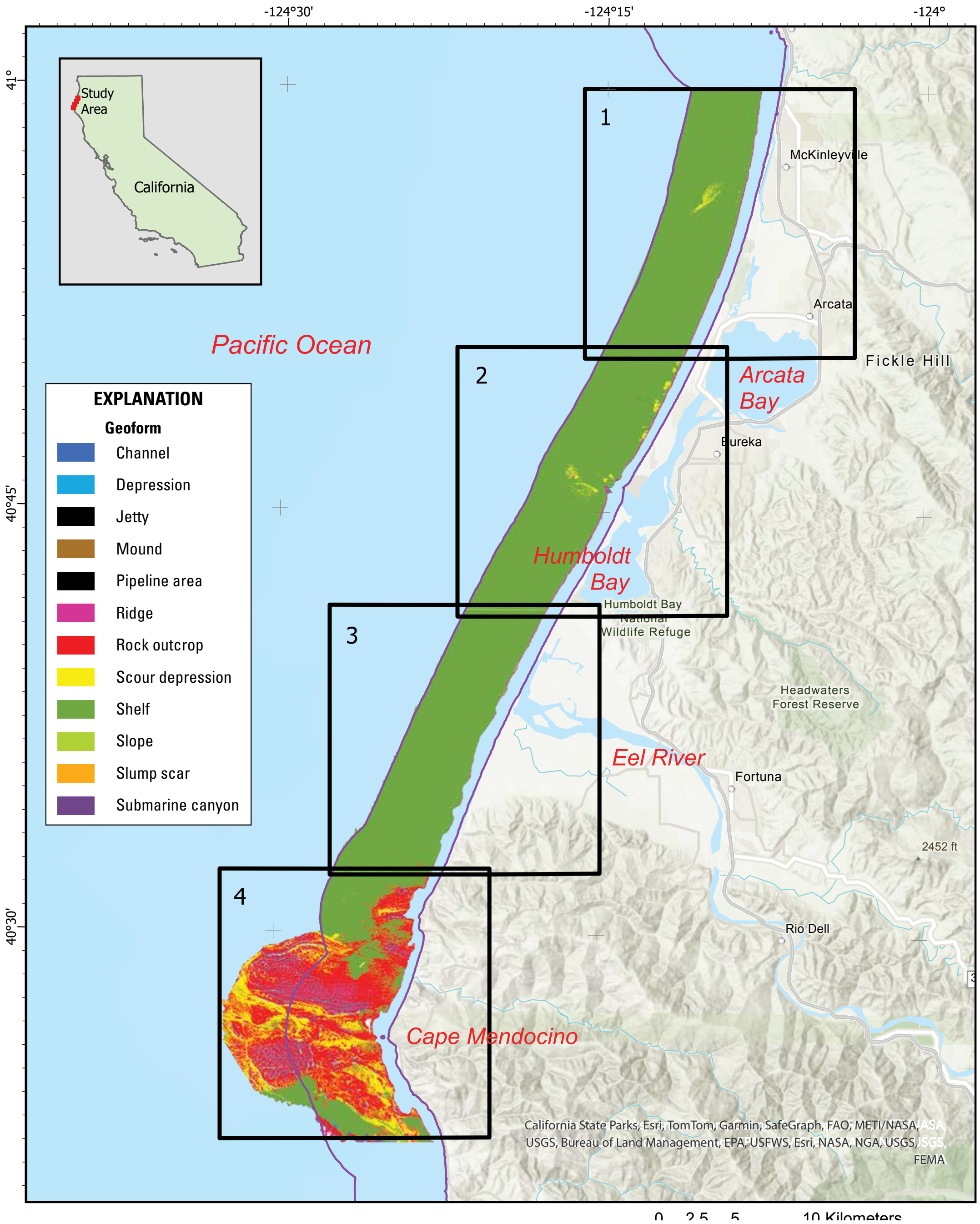

Figure 5. Map showing Coastal and Marine Ecological Classification Standard (CMECS) geoform boundaries in the offshore Humboldt Bay, California, study area (National Oceanic and Atmospheric Administration [NOAA], 2014). Shaded relief derived from bathymetry in Cochrane (2023a, b, 2024a, b). The four California Seafloor Mapping Program blocks in the study area are: (1) Offshore of Arcata, (2) Offshore of Eureka, (3) Offshore of the Eel River, and (4) Offshore of Cape Mendocino. The map blocks are outlined in red, and the boundaries of California State Waters are outlined in purple.

class based on the CMECS induration numerical classification derived, in part, from the backscatter intensity data. Hard-flat areas are predominantly scour depression geoforms.

The geoform composing the largest area in the region is the shelf geoform (72.7 percent, table 4). The shelf areas are flat, soft sediment-covered areas with sediment deposits thick enough to support infauna. The second most extensive geoform is rock outcrop (18.8 percent, table 4). Outcropping bedrock is found only in the southernmost Cape Mendocino map block. Rock outcrop areas were designated a geologic unit based on adjacent terrestrial rocks mapped by McLaughlin and others (2000). They are either Pliocene to Late Cretaceous mélange and sedimentary rocks of the Franciscan Complex or Miocene or Oligocene sedimentary rocks of the False Cape terrane. These rocks are folded, faulted, dipping, and differentially eroded layered rocks that provide excellent habitat for structure-seeking benthic biota.

Scour depression geoforms constitute 4.9 percent of the study area and were assigned based on the observation of one or more of a group of features that includes both larger scale bedforms (for example, sand waves), as well as coarse sediment-filled depressions that resemble both the “rippled scour depressions” of Cacchione and others (1984) and the “sorted bedforms” of Murray and Thieler (2004). These areas are believed to be formed by strong bottom currents flowing from the nearshore to the offshore during storms or high wave activity periods. Scour depression areas are observed in the small interstices formed by the fracture or differential erosion of the sedimentary rock outcrops. Where these interstices contain soft sediment, they are classified as depression geoforms. Anthropogenic geoforms include pipeline areas and jetties. These are situated in the Offshore of Eureka map area.

Table 5 shows the biotic classes logged during video operations. The logging was done with a programmable keypad using the method of Anderson and others (2007). Physical habitat observations were recorded simultaneously as described in the methods section. Three-hundred and eighty-six annotations of organisms and habitat were made from 28 video transects. The combination of biotic and habitat observations could be used to statistically derive biotic groups in the future, but more video data would probably be needed to generate species or biotic-group distribution models.

Single channel seismic reflection data were collected on USGS field activity C109NC (https://cmgds.marine.usgs.gov/fan_info.php?fan=C109NC) as well as video data. The data were interpreted for thickness of sediment above the transgressive unconformity in the Offshore of Eureka and Offshore of Arcata map areas. A sediment thickness raster was included in the data releases for these areas (Cochrane 2024a, b) as well as the seismic data in segy format files. In the Offshore of Eureka area sediment thickness varies from 28.1 m in the southwest deep-water shelf area to 1.7 m in the southeast mapped area closest to shore. In the Offshore of Arcata area, the sediment thickness varies from 17.0 m in the southwest deep-water shelf area to 2.9 m in the northeast mapped area closest to shore.

Table 4. Coastal and Marine Ecological Classification Standard (CMECS) geoforms identified in the offshore Humboldt Bay, California, study area with their total areas of coverage.

[Geoforms are available as a polygon attribute in the companion data releases (Cochrane, 2023a, b, 2024a, b). CMECS classifications from National Oceanic and Atmospheric Administration (NOAA, 2014). m^2, square meter]

Geoform	Description	Area (m^2)	Percent
Gt2p6g9	Channel	8,565,596	1.964563
Gt2p6g14	Depression	387,292	0.088827
Gt2p6a7	Jetty	42,572	0.009764
Gt2p6g39	Mound	152	0.000035
Gt2p6a29	Pipeline area	16,592	0.003805
Gt2p6g48	Ridge	5,434,713.4	1.246479
Gt2p8g48	Ridge	290,472	0.066621
Gt2p6g50	Rock outcrop	82,207,084	18.854608
Gt2p8g50	Rock outcrop	136,560	0.031321
Gt2p6g14.1	Scour depression	21,453,956	4.920573
Gt2p6	Shelf	316,829,262	72.666386
Gt2p6g61	Slope	4	0.000001
Gt2p8g62	Slope	68	0.000016
Gt2p20g55.2	Slump scar	57,256.786	0.013132
Gt2p20	Submarine canyon	583,675.6	0.133869

Table 5. Biota attribute summary for the study area offshore Humboldt Bay, California.

[Biota limited to California Seafloor Mapping Program keypad list of attributes. Latitude and longitude in this report are relative to the World Geodetic System of 1984 (WGS 84). Depth as referred to in this report is relative to mean lower low water (MLLW) from verified tides. Count is the number of observations of the biota in the video. Depth to seafloor in meters (m)]

Attribute	Count	Latitude minimum	Latitude maximum	Longitude minimum	Longitude maximum	DEPTH minimum (m)	DEPTH maximum (m)
cupcoral	25	40.3830	40.4948	−124.5298	−124.4265	23.0073	87.6573
kelp	1	40.4692	40.4692	−124.5152	−124.5152	48.1168	48.1168
encrusting	128	40.3794	40.8439	−124.5280	−124.2402	22.2186	93.7589
tubeworm	5	40.3810	40.4378	−124.5298	−124.4130	49.1620	83.6445
greenling	6	40.4531	40.4764	−124.5112	−124.4909	37.4303	53.7231
crabcncr	34	40.3811	40.7675	−124.5304	−124.3009	15.1607	90.1795
orangepuff	33	40.3816	40.4754	−124.5265	−124.4116	35.5647	83.7551
britin	44	40.4371	40.4771	−124.5295	−124.5050	37.1830	78.0005
hydrocoral	7	40.4572	40.4938	−124.4953	−124.4544	28.9824	38.6089
pinkpias	3	40.3811	40.4958	−124.4541	−124.4129	42.1620	46.9878
fish	19	40.3796	40.4953	−124.5297	−124.4147	22.2186	78.0005
anemonesol	30	40.3794	40.4964	−124.5300	−124.4108	32.2306	85.9638
greypuffba	4	40.4522	40.4769	−124.5052	−124.4913	29.8631	53.7888
sandstar	6	40.7667	40.8443	−124.3019	−124.2411	41.7484	43.9290
seacuc	90	40.3816	40.4970	−124.5298	−124.4115	33.9603	78.0005
briton	1	40.3846	40.3846	−124.4496	−124.4496	84.6458	84.6458
algae	4	40.4297	40.8442	−124.4327	−124.2424	24.9306	43.9290
sponge3D	71	40.3802	40.4768	−124.5305	−124.4115	22.2186	93.7589
seaslug	11	40.3819	40.4742	−124.5272	−124.4118	35.6118	70.7695
hydroid	83	40.3805	40.4953	−124.5298	−124.4115	29.8631	93.7589
crinoid	13	40.4360	40.4681	−124.5305	−124.5205	55.3626	78.8662
crabhermit	5	40.3848	40.7658	−124.4539	−124.3012	41.4552	83.6445
rockfish	46	40.3794	40.4771	−124.5269	−124.4116	24.9306	93.7589
starleath	7	40.3819	40.4760	−124.5245	−124.4118	24.1933	83.7551
driftweed	3	40.3818	40.4957	−124.4964	−124.4120	37.3459	45.7300
stomus	3	40.4387	40.4408	−124.5279	−124.5257	60.4493	76.5722
tunicate	15	40.4301	40.4692	−124.5268	−124.4317	23.0073	68.1710
lingcod	5	40.4306	40.4764	−124.5258	−124.4299	25.9573	60.4493
anemoneagg	2	40.4578	40.4768	−124.5054	−124.4931	32.2306	35.6748
gorg	84	40.3819	40.4952	−124.5279	−124.4116	35.5647	76.5722
frillcuc	15	40.4389	40.4771	−124.5277	−124.4839	38.2542	74.8591
starbask	27	40.3830	40.4695	−124.5298	−124.4276	23.8618	85.9638
bloodstar	19	40.3819	40.4768	−124.5305	−124.4118	23.7691	78.8662
branchbry	11	40.3819	40.4768	−124.5058	−124.4115	32.2306	83.7551
trackstrai	6	40.3797	40.8444	−124.5304	−124.2431	44.1687	78.8662
seapen	9	40.3804	40.3836	−124.4497	−124.4111	43.2780	93.7589
mediaster	45	40.4370	40.4753	−124.5297	−124.4935	35.6118	78.0005
metridium	48	40.3794	40.8438	−124.5269	−124.2408	23.7691	83.7551
seastar	74	40.3820	40.4946	−124.5305	−124.4115	22.2186	78.8662

Table 5. Biota attribute summary for the study area offshore Humboldt Bay, California.—Continued

Attribute	Count	Latitude minimum	Latitude maximum	Longitude minimum	Longitude maximum	DEPTH minimum (m)	DEPTH maximum (m)
flatfish	32	40.3795	40.8442	−124.5304	−124.2411	42.1841	90.1795
bioturb	41	40.3811	40.9198	−124.5300	−124.2007	40.9921	78.6401
anemonetub	1	40.3802	40.3802	−124.4137	−124.4137	50.7467	50.7467
sunstar	18	40.3794	40.4955	−124.5265	−124.4110	22.2186	79.0098

Summary

The U.S. Geological Survey (USGS) provided Coastal and Marine Ecological Classification Standard (CMECS) geoform, substrate, and biotic component geographic information system (GIS) products for the California State Waters in the region of Humboldt Bay. Interest from private companies and State and Federal government agencies motivated this study to provide data to aid in the development of 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.

This project, carried out by the USGS in collaboration with California State University Monterey Bay Seafloor Mapping Lab, resulted in four USGS data releases for individual map blocks that are part of the California State Waters Map Series: Offshore of Arcata, Offshore of Eureka, Offshore of the Eel River, and Offshore of Cape Mendocino. The study area consists of 436 square kilometers (km^2) of multibeam echo sounder (MBES) data that were acquired by Fugro Pelagos, Inc., in 2007. Towed camera-sled video was acquired in 2009 and 2010 to supervise the classification of the MBES data into habitats. Three-hundred and eighty-six annotations of organisms and habitat were made from 28 video transects. Using video observations of habitat as ground-truth, derivatives of the MBES data were classified into 3 substrate induration types, 26 modifier groups, and 15 geoforms. The study area substrate is predominantly soft-flat sediment (mud and fine sand) covering 321.1 km^2 (73.6 percent) of the area. Hard-flat substrate areas, predominantly coarse sediment in scour depressions, constitute 23.5 km^2 (5.4 percent) of the study area. Hard-rugose substrate areas are outcrops of layered sedimentary bedrock and constitute 91.4 km^2 of the study area (20.9 percent). The predominant geoforms mirror the substrate induration results, shelf (flat areas covered in soft sediment), rock outcrop, and scour depression (flat areas covered in coarse sediment formed by bottom currents). The shelf geoform constitutes 72.7 percent, rock outcrop constitutes 18.8 percent, and scour depression geoforms constitute 4.9 percent of the study area. On the flat shelf areas north of Cape Mendocino post-transgressive sediment varies in thickness from 1.7 meters (m) nearshore to 28.1 m offshore.

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