Marine Benthic Habitat Mapping of the Point Reyes National Seashore

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1. Introduction

For generations maps have told tales that words and numbers alone cannot. Maps guided us to the New World, helped us navigate from its edges into its interior. Vague, undefined maps showed Lewis & Clark where to go next – and in turn gave us fresher, more accurate maps that fueled further explorations. Maps outline the frontier for settlement and showed us where to find the silver, the gold and the coal that made us prosperous. Computer mapping helps businesses expand, prosper, and fine new customers (Anthony, 2009).

Maps of the sea floor aid in the understanding, conservation and exploitation of marine resources. In response to the U.S. National Park Service's (NPS)[1] interest to map the submerged lands within park boundaries and to understand the processes that play a role in the formation, distribution and disturbances of both coastal and submarine resources in and around park boundaries, we developed marine thematic maps that can be used by NPS personnel to manage resources. The tasks involved the compilation of all available seafloor mapping data in and around the Point Reyes National Seashore (PORES) that include, but are not necessarily limited to, marine acoustical data, such as multibeam echosounder (MBES) bathymetry and backscatter data, side-scan sonar mosaics, and sediment sample information; the interpretation of recently collected data; and the construction of habitat and geologic maps.

1.1 Goal

This project had three objectives: to compile available regional seafloor mapping data for the Point Reyes National Seashore area and to interpret newly collected data provided through the California State Mapping Program (CSMP) and the United States Geological Survey (USGS) to construct benthic habitat and geologic maps of the submerged lands of the PORES. The habitat maps were constructed using the same habitat classification scheme and mapping code presently being used for the development of the CSMP habitat maps (Greene et al., 1999, 2005, 2007) and used for the construction of the NPS potential habitat maps of the Golden Gate National Recreational Area (Greene et al., 2010). The

[1] Funding provided by the NPS Inventory and Monitoring Program

maps comprise an integration of previous seafloor maps such as the nearshore habitat and substrate maps of Erdey-Heydone (2007).

1.2 Geologic Setting

The Point Reyes National Marine Seashore occupies most of the Point Reyes Peninsula, a hook-shaped landmass that projects into the Pacific Ocean northwest of the Golden Gate (Fig. 1). This land mass is comprised of Cretaceous granites belonging to an exotic granitic basement block known as Salinia and overlain by Tertiary marine sedimentary rocks (Page, 1970). This allochthonous, or out-of-place, block is known as a tectonostratigraphic terrane, which has been moved into place by plate motion along faults of the San Andreas Fault System, a transform fault that separates the Pacific Plate on the west from the North American Plate on the east. The Pacific Plate is moving north relative to the American Plate (Atwater, 1970), or to the right as you face the fault. In the past 10 million years or so Point Reyes has moved about 150 km along the San Gregorio and central San Andreas faults from a position to the south where it was attached to Point Lobos on the Monterey Peninsula (Greene and Clark, 1979; Dickenson et al., 2005).

1.3 Previous Work

The Point Reyes Peninsula is a well-studied region, with research ranging from geology, biology and cultural features (Gilliam, 1962; Galloway, 1977; Clark et al., 1984; Clark and Brabb, 1997; Blake et al., 2000; Bruns et al., 2002; Grove and Niemi, 1999; Pacific States Marine Fisheries Commission, 2010; Ryan et al., 2010). Although work has been done in describing and mapping intertidal and terrestrial habitats, little effort has been devoted to deep-water nearshore habitats. Erdey-Herdon (2007) constructed the first deep-water marine benthic habitats along selected nearshore areas of the park (Figs. 2 and 3). This is the first mapping effort to characterize the marine benthic habitats of the entire Point Reyes National Seashore.

Major seafloor mapping efforts are underway in California State waters to identify and image marine benthic habitats and geology for establishing Marine Protected Areas (MPAs) mandated under the California Marine Life Protection Act (MLPA) and the California Ocean Protection Act (COPA) Since many of the NPS lands in California are located in State waters, it was an excellent time to take advantage of the California mapping effort and to integrate these data to produce interpretive potential habitat maps of interest to the NPS. In addition, the USGS, California State University Monterey Bay (CSUMB) Seafloor Mapping Lab, and the CSMP had done considerable mapping in the past, however little of the area under NPS jurisdiction has been mapped. In shallow water bays and inlets the USGS has undertaken MBES mapping, sediment sampling and video surveys.

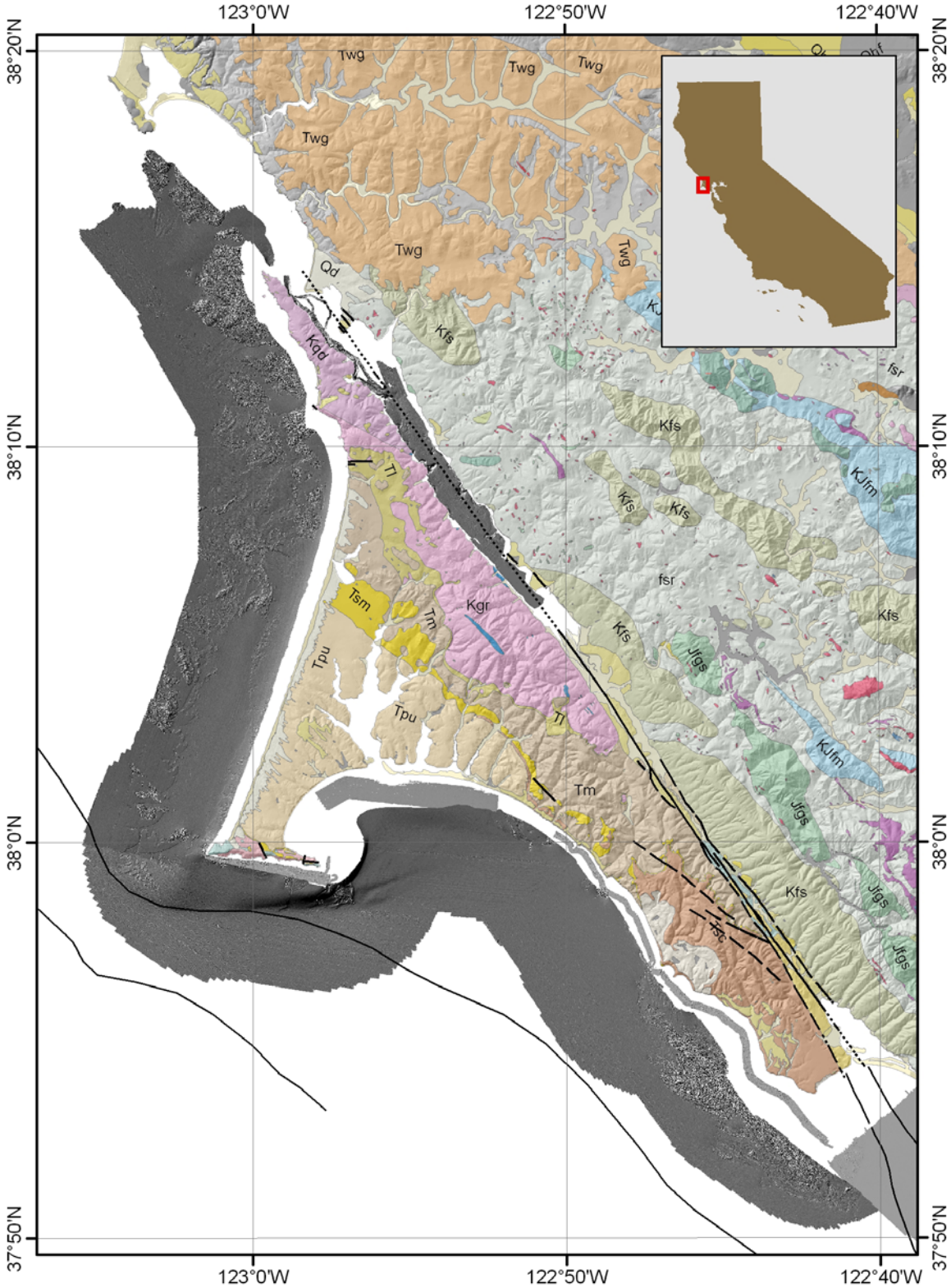

Figure 1. Map showing the onshore geology of the Point Reyes National Seashore (See Map Sheet 4 for explanation of geologic units). Modified after Clark and Brabb (1977).

Figure 2. Area of coverage of interferometric side-scan sonar data collected with a GeoSwath 240 kHz bathymetric mapping system used by MLML Center for Habitat Studies initial marine benthic habitat characterization study (Modified after Erdey-Herdorn, 2007).

2. Methods

Three meetings were held at the PORES headquarters in Point Reyes Station to produce guidelines on how the habitat mapping exercise would proceed and to obtain input from all partners. The first meeting occurred March 25, 2010 prior to the actual compilation of the maps and was used to "kick-off" the project by establishing a dialog between partners (NPS/PORES and Moss Landing Marine Labs (MLML)/Center for Habitat Studies) to assure good communications and coordination within the project. The second meeting was held August 24, 2010 where draft products were reviewed and changes suggested. A final workshop was held January 21, 2011 to initiate the final review of the map products

and to solicit input on how the final products should be presented. Final comments were received on February 11, 2011.

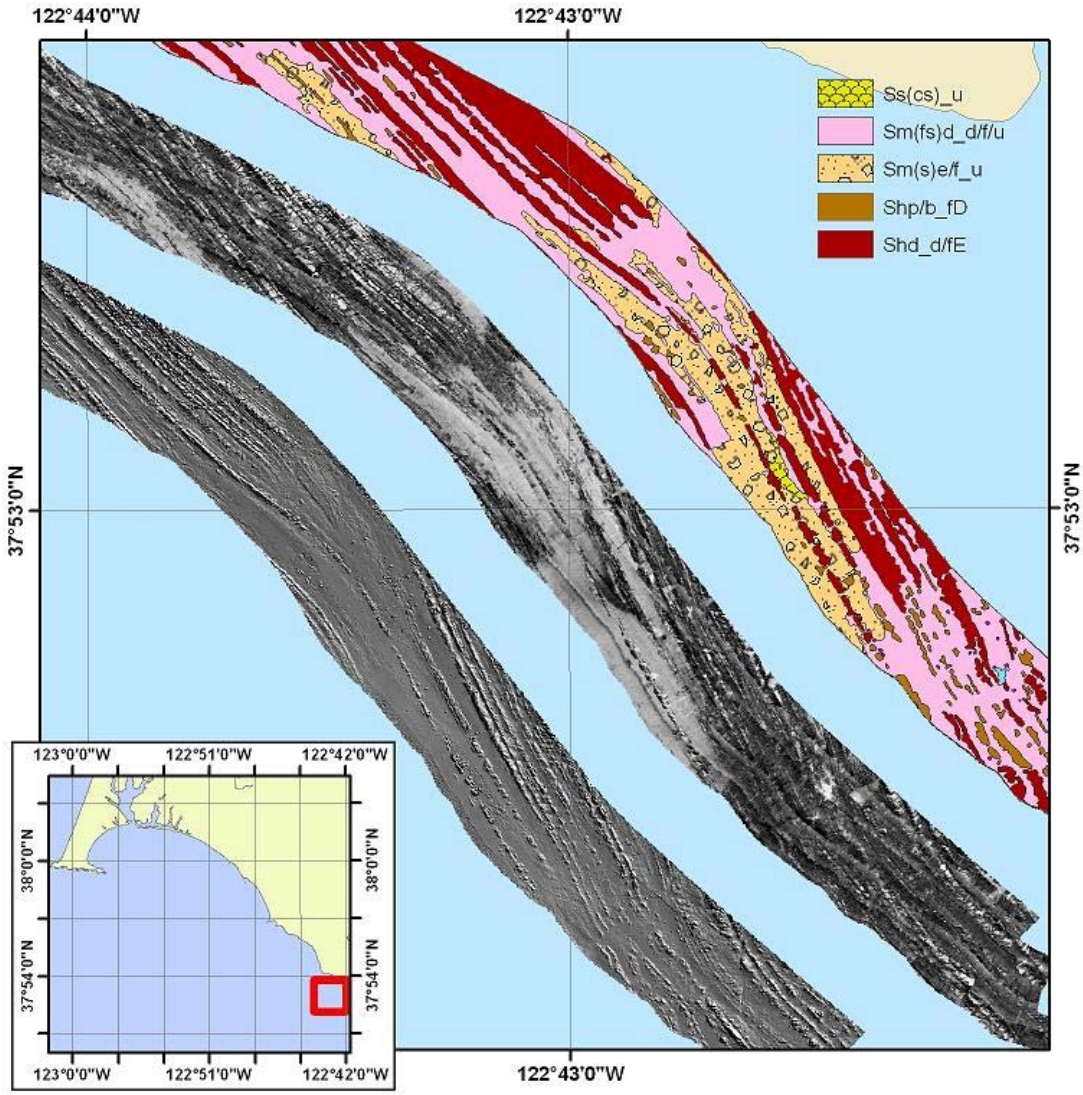

Figure 3. Example of data and interpreted habitat types collected by a GeoSwath 240 kHz seafloor mapping system that was used in the compilation of the PORES habitat map. Outside strip is interferometric bathymetry, center strip is side-scan sonar mosaic, and inner colored strip is interpreted habitats. (After Erdey-Herdone, 2007).

As a base for our interpretations we used the habitat maps constructed by Erdey-Heydorn (2007) and the following data sets:

- MBES data collected by the Seafloor Mapping Lab of CSUMB;
- USGS interferometric side-scan sonar and bathymetry data sets;
- National Oceanographic and Atmospheric Administration (NOAA) MBES and point soundings bathymetry from the National Geophysical Data Center (NGDC) Hydrographic Data Base;

- LiDAR from the National Aeronautical and Space Administration (NASA) Wallops Flight Facility and USGS; and
- LiDAR from NOAA Coastal Services Center, Wallops Flight Facility and USGS.

Other data sets used to compile the base maps include the following:

- Kelp Canopy data from The Resources Legacy Fund Foundation and California Department of Fish and Game;
- Coastal Biophysical Inventory of the shoreline from Coast Science and Learning Center (2007)
- Video from towed camera sled collected by the USGS in 2007 and 2008;
- ROV video collected for the Pacific States Marine Fisheries Commission (2009); and
- Sediment sample information provided by the USGS obtained in 2005 and from the 2006 usSEABED data set.

See Map Sheet 6 for data location and specifics and Appendix I).

2.1. Geophysical Data Sets

We used MBES data sets from the USGS, NOAA, CSUMB Seafloor Mapping Lab, and digital wide swath side-scan sonar data collected by MLML, and LiDAR data for shore and onland imaging (Fig. 4). These data formed the basis for our geology and habitat interpretations (see Map Sheets 4 and 5). Specifically these data are:

- MBES bathymetric grids and backscatter collected within Tomales Bay by the USGS;
- Bathymetric grid of point soundings housed at NOAA's NGDC for Tomales Bay;
- NOAA MBES data collected in Drakes Bay;
- MBES data sets collected recently for the CSMP in blocks 28, 29 and 30 by CSUMB Seafloor Mapping Lab; and
- Wide-swath interferometric bathymetry and side-scan sonar data collected in 2005 around Point Reyes Headlands and from Drakes Bay to Duxbury Reef.

We also used for a Master of Marine Sciences thesis by Mercedes Erdey-Herndone (2007) of MLML, Center for Habitat Studies, and seafloor sediment samples collected in 1998 and 2002-2008 by the USGS.

Merging distinct, overlapping data sets for habitat interpretations was not possible because of temporal differences in data collections. Strong ocean currents north and around Point Reyes Headlands create a dynamic, sedimentary environment with major bedforms that often shift in position and shape. This dynamic seafloor activity precludes combining data collected at different times into a single substrate or benthic habitat map. We essentially used the various data sets to fill data voids and to verify the more stable substrate types. Time-series analyses were not made because repeat surveys were not considered.

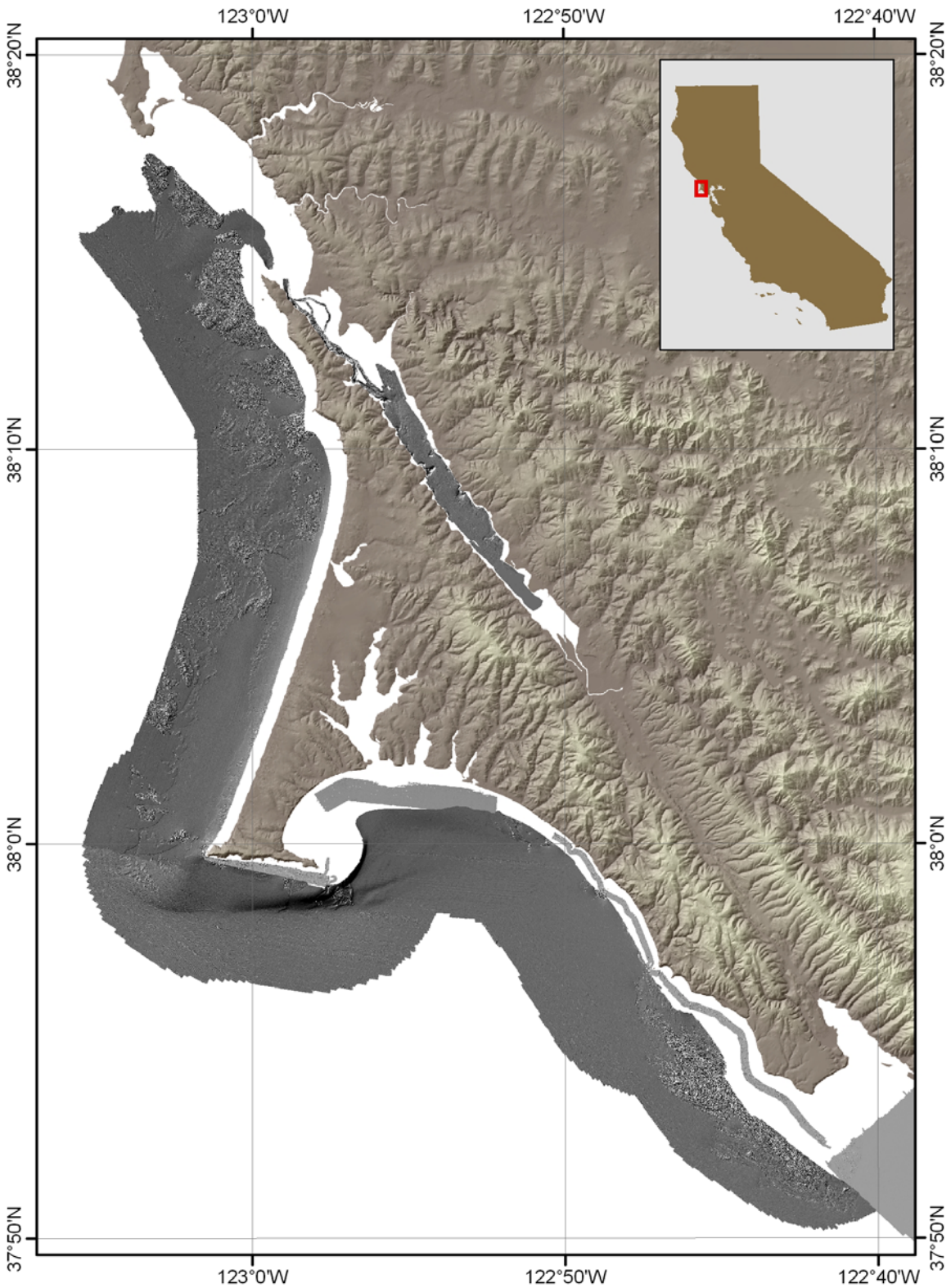

Figure 4. Map showing areas of geophysical data interpreted for the construction of the geologic and marine benthic habitat maps. White areas inshore are data gaps and areas where geologic and habitat interpolations were made.

2.1.1. USGS Side-Scan Sonar and Bathymetric Data

Interferometric bathymetry and digital side-scan sonar mosaics gridded at 2 meters were produced from surveys undertaken by the USGS in November 2004 and November 2005. These data obtained from the USGS web site are restricted to Tomales Bay and provided significant data for the interpretation of the habitat map in that area.

2.1.2. NOAA Multibeam Echosounder and Point Soundings Bathymetry

MBES data gridded to a 1-m cell size, covering part of Drakes Bay in water depths of about 5 to 20 m were used to construct both the geology and habitat maps. These data were obtained from NOAA. Point shapefile of bathymetric soundings for the entire map area were obtained through NGDC's Hydrographic Survey Database, which includes surveys undertaken by the National Ocean Service (NOS).

2.1.3. CSUMB Seafloor Mapping Lab Multibeam Echosounder Bathymetry

A Reson SeaBat 7125 duel frequency (200/400 kHz) MBES mapping system was used to collect bathymetric data in the CSMP mapping blocks 28, 29 and 30 offshore from Bolinas Lagoon to Duxbury Reef. Depth grids created from bathymetric surveys were processed to a horizontal resolution of 1-2 m. Backscatter intensities are represented by 255 levels of gray (8-bit) and were processed into mosaics with a pixel size of 1-m. Brighter shades represent high backscatter (generally harder seabed) while darker shades represent low backscatter intensities (generally softer seabed). All data were compiled and displayed for interpretation using ESRI ArcGIS® software, ArcMap® v.9.2. The process utilizes editing a shapefile within ArcMap, beginning with the construction of polygons to delineate benthic features. A feature is an area with common characteristics, which can be mapped as a single potential habitat type or geologic unit. The boundaries and extents of these features were determined from the bathymetric data. Generally, interpretations were made at less than 1:2000.

2.1.4. Moss Landing Marine Labs, Center for Habitat Studies Side-Scan Sonar Data

Side-scan sonar data collected by MLML Center for Habitat Studies in 2005 were also used to create maps of seafloor habitats. These data were collected using a GeoAcoustic® Inc. 250 kHz GeoSwath® multibeam side-scan sonar mapping system. GeoSwath is an amplitude and phase measuring system, which acquires side-scan sonar and interferometric bathymetric data. These data were generally of high quality and facilitated interpretation of the textural characteristics of the seafloor area depicted.

2.2. Sediment and In Situ Observational Data

2.2.1. USGS Sediment Samples

Sediment sample information provided by the USGS (usSEABED) was used to validate the acoustic geophysical data interpretation and to groundtruth the geology and potential habitat types (Reid et al., 2006). Anima et al. (2008) obtained several grab samples from Tomales Bay in 2005 that were used for verifying sediment interpretations from the USGS backscatter dataset.

2.2.2. USGS Bottom Camera Observations

The USGS collected video of the seafloor in selected areas offshore of PORE in 2007 using a towed camera sled (see Map Sheet 6 for location of transects). These data were used to “groundtruth” or validate interpretations made from the geophysical data and to further refine the habitat types. Visual observations of the seafloor character (benthic habitat), flora, and fauna, obtained by the USGS in 2008, were used to confirm habitat interpretations.

2.2.3 Pacific States ROV Video Observations

The California Department of Fish and Game collected video of the seafloor offshore of PORE in 2009 (see Map Sheet 6 for location of transects). These data were also used to confirm habitat types and substrate character.

2.3. Interpretation Methods

High-resolution multibeam sonar data in the form of bathymetric depth grids (seafloor digital elevation models, referred to as the "bathymetry") were the primary data used in the interpretation of potential habitat types and geologic features. Shaded relief imagery ("hillshade") allows for visualization of the terrain and interpretation of submarine landforms. Based on the hillshades, areas of rock were identified by their often sharply defined edges and high relative relief; these may be contiguous outcrops, isolated portions of outcrop protruding through sediment cover (pinnacles and rocks), or isolated boulders. Although these features can be confidently characterized as exposed rock, it is not uncommon to find areas within or around a rocky feature that appears to be covered by a thin veneer of sediment. These areas were identified as "mixed" induration, containing both rock and sediment. Broad areas of the seafloor lacking sharp and angular characteristics are considered to be sediment. Sedimentary features may contain erosional or depositional characteristics recognizable in the bathymetry, such as dynamic bedforms (dunes or sand waves). General morphologic features such as scours, mounds, and depressions were also identified using the hillshade relief imagery.

The combination of acoustic backscatter data and "groundtruthed" sediment samples were used to delineate seafloor sediment types within areas identified as "soft (s)" induration. Initially, groundtruth data, in the form of grab sample descriptions and

average grain size measurements, were categorized into four grain-size categories: mud (m), muddy sand (s/m), sand (s), and sandy gravel (s/g). Backscatter data were then classified into four intensity categories (low, medium, high, very high) that are assumed to correspond to relative grain sizes. This intensity classification of the seafloor correlated with data from the sediment samples. The combination of remotely observed data (acoustic backscatter) and directly observed data (sediment grab samples) translates into higher confidence in our ability to interpret broad areas of the seafloor. Nonetheless, we caution against using the sediment type interpretations as anything more than "best-guess" due to the following issues: 1) characterization of contiguous sediment bodies is a difficult procedure since even small areas can exhibit a wide spectrum of backscatter intensity values that lack distinct boundaries; 2) backscatter intensity can be affected by depth, vegetation, water column conditions, and seafloor relief; and 3) directly observed sediment data (sediment samples) representing a very small area were interpolated to broad areas of remotely observed data.

The term "white zone" refers to the nearshore marine zone where multibeam bathymetric sonar data were not collected due to navigational hazards and/or shallow water. The width of the white zone, which stretches along the entire coastline, is typically constrained by water depth with the -10 m contour, the approximate offshore boundary. Thus, the edge of the white zone can range from tens of meters to hundreds of meters offshore. The landward edge of the white zone is determined by the land boundary, which includes all rocks and islands above the water surface.

Due to the lack of detailed bathymetric information, seafloor characterization of habitat and geology within the white zone must rely upon other sources of data. Within the Point Reyes National Seashore, our methods focused on the use of airborne LiDAR (Light Detection And Ranging) data, seafloor samples, georeferenced aerial imagery, terrestrial geology maps, and the Coastal Biophysical Inventory completed by the Pacific Coast Science and Learning Center in 2007. Seafloor characterization of the white zone required extensive interpolation from existing datasets. The following paragraphs describe how we used the various datasets were used to create a white zone benthic habitat and geology interpretation:

> Sun-illuminated DEM's were created from the terrestrial LiDAR datasets and were primarily used to assess coastal topography and large islands. The LiDAR data were not useful for interpreting any submerged features.
>
> The most comprehensive dataset was the georeferenced aerial orthophotos, publicly available from the MarinMap/County of Marin GIS data site (http://mmgis.marinmap.org). Images were downloaded at 1-m resolution. Sixty-six image tiles covered the entire length of the mapped coastline. The images were loaded into ArcMap v.9.3 and provided good detail of the coastline environment. Useful information gathered from the image tiles was the presence, or absence, of frothy water tens of meters offshore that indicated where areas of submerged rock that extended offshore from coastal bluffs and rocky headlands. Zones of turbulent water suggest the presence of barely submerged rocky features,

such as boulders and/or bedrock pinnacles. Also apparent in the image tiles were steep, non-vegetated coastal bluffs that suggest recurring episodes of weathering and failure. The base of these bluffs, and the nearshore zones, were typically strewn with boulders and other landslide debris (colluvium), and were characterized as such.

Alongshore beach transects, completed in 2005 as the Coastal Biophysical Inventory (CBI) by the Pacific Coast Science & Learning Center in cooperation with the Point Reyes National Seashore and the Golden Gate National Recreation Area, were helpful in determining the dominant substrate in the shallow subtidal environment. See Kinyon and Gaddam (2007) for more information regarding this dataset. The CBI transects were direct observations that could be correlated with visual analysis of the orthoimagery.

For the onshore side, digital geological maps were overlaid (with transparency) above a hillshaded relief terrestrial DEM. Similarly, interpretive geology and habitat layers offshore were overlaid above a hillshaded relief bathymetric DEM. Features like rocky promontories on the land side were connected to adjacent outcrops visible in the bathymetric data by an arbitrary line drawn across the white zone, creating a polygon. Beaches were connected to areas of sandy seafloor in a similar fashion. Where sediment samples were collected, these data were used to corroborate the interpolation and provide information used to attribute the interpretive polygon.

In places, water in the aerial imagery had sufficient clarity to reveal bathymetric features. Where a feature could be identified in the imagery as a submerged feature, it was identified as such and given geological and habitat-type characterization. Geological attributes of submerged features visible in the aerial imagery were based on the geologic maps of the adjacent coastline.

The interpolation of data for the white zone using the adjacent terrestrial and bathymetric datasets provides reasonably reliable divisions of the region into distinct features. As a cautionary note, however, all demarcations and boundaries for the interpolated area are subjective and arbitrary, and should be seen as approximate, queried, and uncertain.

Areas of the white zone on the maps and in the perspective views of the seafloor that were interpolated can be indentified as the smooth, clean colored areas.

3. Results

The primary result of this work is a series of maps that include MBES bathymetry seafloor relief images, DEM, acoustic backscatter, interpretive potential marine benthic habitat, onshore-offshore geology and specific areas of interest. The title of the map series is “Point Reyes National Seashore Seabed Classification Map Series”, edited by H.

Gary Greene with multiple authors for each map sheet. Seven map sheets are included in the series as listed below:

Map Sheet 1. Endris, C, Dieter, B., Maher, N. and Carlson, C. (Compilers), 2011. Sun-illuminated (315° azimuth) Bathymetry, Map 1 of 6. In Greene, H.G., (ed.), Point Reyes National Seashore, Seabed Classification Map Series Final Report to NPS/PORE, Point Reyes Station, scale 1:48,000.

Map Sheet 2. Endris, C., Dieter, B., Maher, N., and Carlson, C. (Compilers), 2011. Color-coded Bathymetry with Contours, Map 2 of 6. In Greene, H.G., (ed.), Point Reyes National Seashore, Seabed Classification Map Series Final Report to NPS/PORE, Point Reyes Station, scale 1:48,000.

Map Sheet 3. Endris, C., Dieter, B., Maher, N., and Carlson, C., 2011 (Compilers). Acoustic Backscatter Imagery, Map 2 of 6. In Greene, H.G., (ed.), Point Reyes National Seashore, Seabed Classification Map Series Final Report to NPS/PORE, Point Reyes Station, scale 1:48,000.

Map Sheet 4. Endris, C., H.G., Dieter, B., Maher, N., and Carlson, C. (Compilers), 2011. Onshore-Offshore Geology Map, Map 4 of 5. In Greene, H.G., (ed.), Point Reyes National Seashore, Seabed Classification Map Series Final Report to NPS/PORE, Point Reyes Station, scale 1:48,000.

Map Sheet 5. Endris, C., Dieter, B., Maher, N, and Carlson, C. (Compilers), 2011. Potential Marine Benthic Habitats. In Greene, H.G., (ed.), Point Reyes National Seashore, Seabed Classification Map Series Final Report to NPS/PORE, San Francisco, scale 1:48,000.

Map Sheet 6. Endris, C., Dieter, B., Maher, N., and Carlson, C. (Compilers), 2011. Data Sources Map. In Greene, H.G., (ed.), Point Reyes National Seashore, Seabed Classification Map Series Final Report to NPS/PORE, Point Reyes Station, scale 1:48,000.

Map Sheet 7. Endris, C., Dieter, B., Maher, N., and Carlson, C. (Compilers), 2011. Perspective views of potential marine benthic habitat classifications. In Greene, H.G., (ed.), Point Reyes National Seashore, Seabed Classification Map Series Final Report to NPS/PORE, Point Reyes Station, scale 1:48,000.

4. Geologic Map

The Point Reyes Peninsula is located on the transform boundary between the Pacific and North American plates. The San Andreas Fault Zone represents this boundary with concealed traces of faults (shown on the Geologic Map), oriented and extending offshore northwest from land (Ryan et al., 2008). The San Gregorio Fault (an ancillary fault to the

San Andreas Fault Zone) connects to the San Andreas Fault south of the mapped area and is considered part of this major fault zone.

The striking difference of the geology on either side of the San Andreas Fault Zone is apparent in the map where a distinct color contrast occurs (Fig. 1; see Map Sheet 4). On the eastern side of the fault zone the cool grays and blues represent older Jurassic-Triassic Franciscan Complex rocks of serpentine, greywacke and greenstones. On the western side of the fault zone, the warm pinks and browns represent the younger Cretaceous granites of Salinia and the overlying Tertiary sedimentary rocks as mapped by Clark and Brabb (1997). Offshore, to the three-mile state boundary, the geology is dominated by the recent marine sediments (yellows) in and around Drakes Bay, which form dynamic submarine sand dunes off the western tip of Point Reyes. Granitic rocks and conglomerate (pinks and blues) crop out on the seafloor in the nearshore regions of the Point. To the north of Point Reyes the modern marine sediment gives way to deformed Tertiary sedimentary rocks (bluff and browns) that become more folded near the San Andreas Fault zone and where they lap onto the granitic rocks (pinks) that are well exposed offshore in the north. In the south well-bedded and deformed Tertiary sedimentary rocks (browns) crop out on the seafloor and are locally covered with a thin layer of modern marine sediment.

Seafloor geology in the offshore (continental shelf) is primarily composed of Quaternary unconsolidated sediment dominated by sand; west and north of Point Reyes seafloor geology is composed of dynamic bedforms, such as sediment waves and dunes located in a high-energy current and wave zone produced from strong NW ground swells (Fig. 5). Bedrock and basement rocks crop out along the coastline at Point Reyes Headland and in the north of the mapped area from Elephant Rock to Tomales Bluff. Rock exposures comprising of Cretaceous granite and upper Tertiary (Neogene) folded sedimentary rocks are present on the seafloor along this stretch of the coast. Folded Tertiary sedimentary rocks are dominant from Double Point to the mouth of Bolinas Bay.

4.1. Designation of offshore geologic features

Quaternary units that are actively evolving features or materials deposited in the Quaternary time are identified as Quaternary (Holocene). Other units identified as Quaternary only cannot be conclusively interpreted as active based on the data and information available at the time of this study, but are likely not completely static. The symbol 'Q(g)s' is also used wherever sediment is identified as coarser than mud, silt or fine-grained sand based on acoustic backscatter intensities. The symbol 'Qsed' refers to all areas of sediment that are acoustically uniform and morphologically smooth, flat or featureless. Groundtruthing data such as sediment samples and seafloor video are often used to verify the interpretations from geophysical data. They exist at point locations in many places within the mapping area, but the resolution of that information is too sparse to fully characterize the large expanse of the mapped Quaternary sediments. Generally 'Qsed' areas comprise of mud and sand with biogenic clasts interspersed.

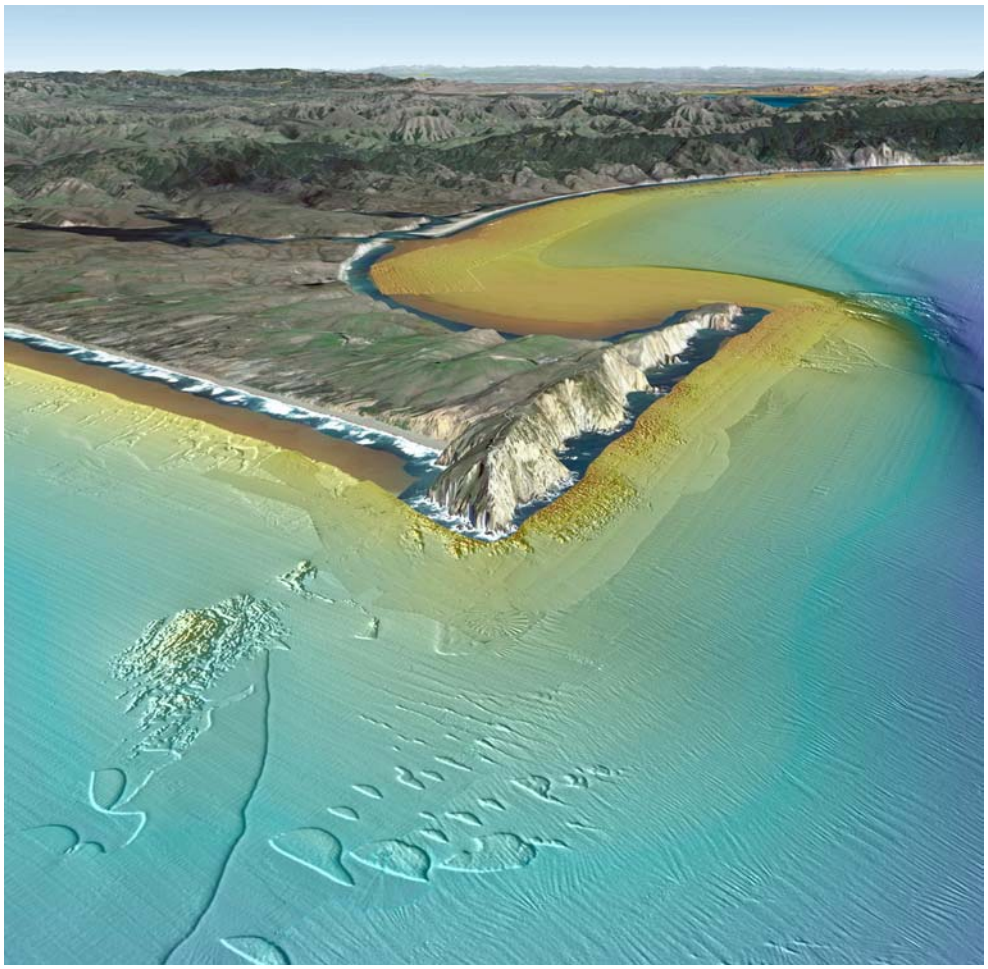

Figure 5. A MBES bathymetric image showing dynamic bedforms of mobile sand sheets and dunes being swept by bottom currents around Point Reyes Headlands. Note bedrock outcrop on seafloor that is an extension of the headland. Striations on seafloor are artifacts from the roll of the survey vessel.

Bedded strata of Tertiary age are identified at both the north and south ends on the shelf areas offshore of PORE. Identification of Pliocene Purisima ('Tp') Formation and its equivalent unit, the Santa Cruz Mudstone (‘Tsc’), and Miocene Monterey Formation ('Tm'), as well as the undifferentiated Tertiary sedimentary deposits (‘Tu’) of possible Pliocene age and the Eocene Point Reyes Formation (‘Tpr’), a conglomerate of similar age and lithology to the Carmelo Formation of the Carmel Peninsula were made by a combination of extending terrestrially mapped units offshore along known structural boundaries (faults) where bedded outcrops are identifiable and from their surface textures. Differentiation between Monterey and Purisima formations offshore is possible due to the juxtaposition of their distinct stratigraphy along fault contacts (contacts which reflect similar lithostratigraphic differences on land). The Purisima formation is more

massively bedded and is generally less folded than the thinner more tightly inter-layered and folded Monterey and Santa Cruz Mudstone formations, which is evident in the multibeam imagery.

The symbol 'TKu' is used where the likelihood of Cretaceous to Tertiary age rocks are expected to be found based on the mapped units stratigraphic relationship to adjacent units and when good rock samples of the unit are not available. Generally these are isolated boulders or bedrock pinnacles protruding through sediment cover in the northwest corner of the mapped area. At this location, the 'TKu' designation is used to identify a rock type due to indistinct morphology as well as discontinuous or heterogeneous outcrops and no good relationship to adjacent terrestrial units.

The Cretaceous crystalline basement rocks are granite or granodiorite and are characteristic of the Salinian tectonostratigraphic terrane, which is bound in this region by the San Andreas Fault Zone along the eastern margin of this basement rock. The granitic rocks ('Kgr') have a distinct crosshatch, subangular surface texture, which is identifiable in several outcrops offshore of Point Reyes Headland and offshore of Tomales Bay entrance.

Where Cretaceous and Tertiary bedrock appear to be locally covered with sediment we mapped them as independent units (i.e., ‘Q/Tp’, ‘Q/Tsc’, ‘Q/Tm’, Q/Tpr’, ‘Q/Tu’, ‘Q/Kgr’). These units are generally found in the nearshore areas where sediment is continuously being transported along the coast as littoral drift. These areas are ephemeral and may at other times be either completely covered with sediment or completely exposed as hard bedrock.

Franciscan Complex rocks ('KJf') are located onshore east of the San Andreas Fault Zone and comprise highly heterogeneous metamorphosed rocks offscraped from the earlier downgoing subduction slab. A variety of protolithic rock types, including greywacke, limestone, serpentinite, shale, basalt and gabbro, were subjected to deep burial and metamorphism during plate subduction. The metamorphosed form of these rocks as well as mélange units comprise the Franciscan Complex and have been dated as Jurassic to Cretaceous in age. However, rock types that make up the Franciscan Complex could not be identified using the acoustic data, and since the San Andreas Fault Zone is known to separate the Cretaceous granitic basement rocks from the Franciscan Complex it is not surprising not to find these rocks offshore of the park.

Few anthropogenic units were identified and mapped based on appearance in multibeam bathymetric hillshaded relief imagery, combined with information about known activities past and present occurring in the region.

5. Habitat Map

The habitat map shows “potential” marine benthic habitats, representing substrate types, geomorphology, and seafloor processes that may define suitable habitat for a specific species or an assemblage of species. A habitat map is based largely on seafloor geology

(Sheet 4) and integrates information from the high-resolution bathymetry (Sheets 1 and 2) and backscatter (Sheet 3) maps and groundtruthing information, such as bottom samples and seafloor photos/video (Sheet 6). The combination of remotely observed data (e.g., multibeam echosounder bathymetry and backscatter) and directly observed data (e.g., camera transects and sediment grab samples) gives higher confidence in the interpretation of the seafloor.

Habitats were classified using the Benthic Marine Potential Habitat Classification Scheme, a mapping attribute code developed by Greene and others (1999, 2007). The classification scheme uses a coding system to distinguish marine benthic habitats and to facilitate search queries within a GIS. The code encompasses a broad spatial scale when defining a habitat and uses letters that are intuitive to the reader. For example, the following categories of the code are used to describe a single habitat within a scale that ranges from tens of kilometers to one meter: Megahabitat (**S**helf and **E**stuary), Seafloor Induration (**h**ard, **s**oft, **m**ixed), Meso/Macrohabitat (e.g., **e**xposed rock), and Modifier (e.g., **g**ranite). Not all categories are required or applicable given the study objectives, data availability, or data quality. For further explanation of the habitat characterization scheme, see Appendix II.

Thirty-nine potential benthic habitat types covering 428.7 km^2 were defined from the interpreted data; 11 are located in estuaries and 28 on the continental shelf. Potential habitats range from hard basement and bedrock seafloor outcrops (Figs. 6 and 7) to soft (unconsolidated) sand dunes and marine sediments locally covering bedrock. The most extensive potential habitat type is soft unconsolidated sediment; it covers 331.5 km^2 (77% of total) of the shelf and 16.1 km^2 (4%) of the estuaries. Hard rock exposures occur predominantly in the offshore on the shelf where 44.5 km^2 (10%) are deformed (folded and faulted) sedimentary rock (Fig. 8) and 21.9 km^2 (5%) are granitic basement rock. Rock outcrops and rubble are the primary habitat type for recreationally and commercially important rockfish and lingcod (*Ophiodon elongatus*) (Cass et al., 1990; Love et al., 2002). Dynamic bedforms such as sand waves are considered potential foraging habitat for juvenile lingcod and possibly migratory fishes (Beaudreau, 2005), as well as for forage fish such as Pacific sand lance (Blain, 2006).

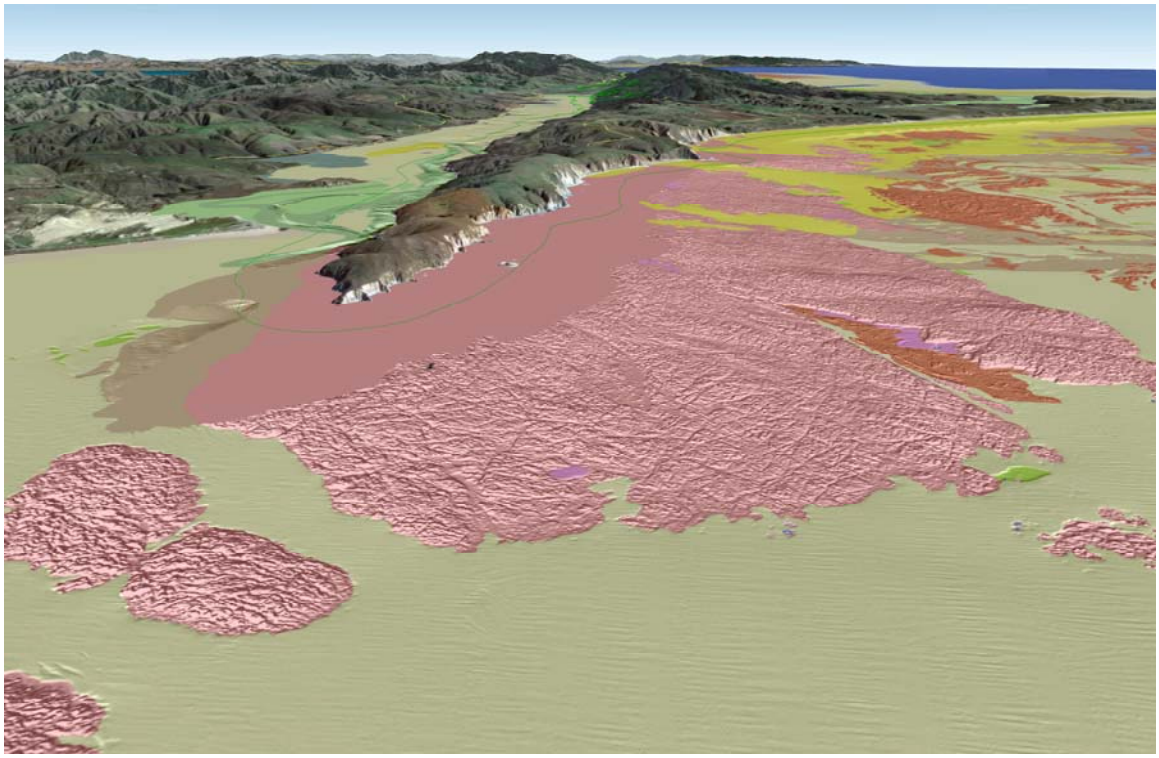

*Figure 6. Hard Cretaceous granitic (pink) and deformed Tertiary (brown) outcrops north of Point Reyes and west of Tomales Point that form good rockfish (*Sebastes *spp.*) *benthic habitat. View looking southeast. Smooth, clean colored areas are the white zone (data gaps) that is filled from interpolation of known geology and habitats onshore and offshore. Repetitious stripping in foreground is an artifact of roll error that has not been eliminated by MBES post-processing.*

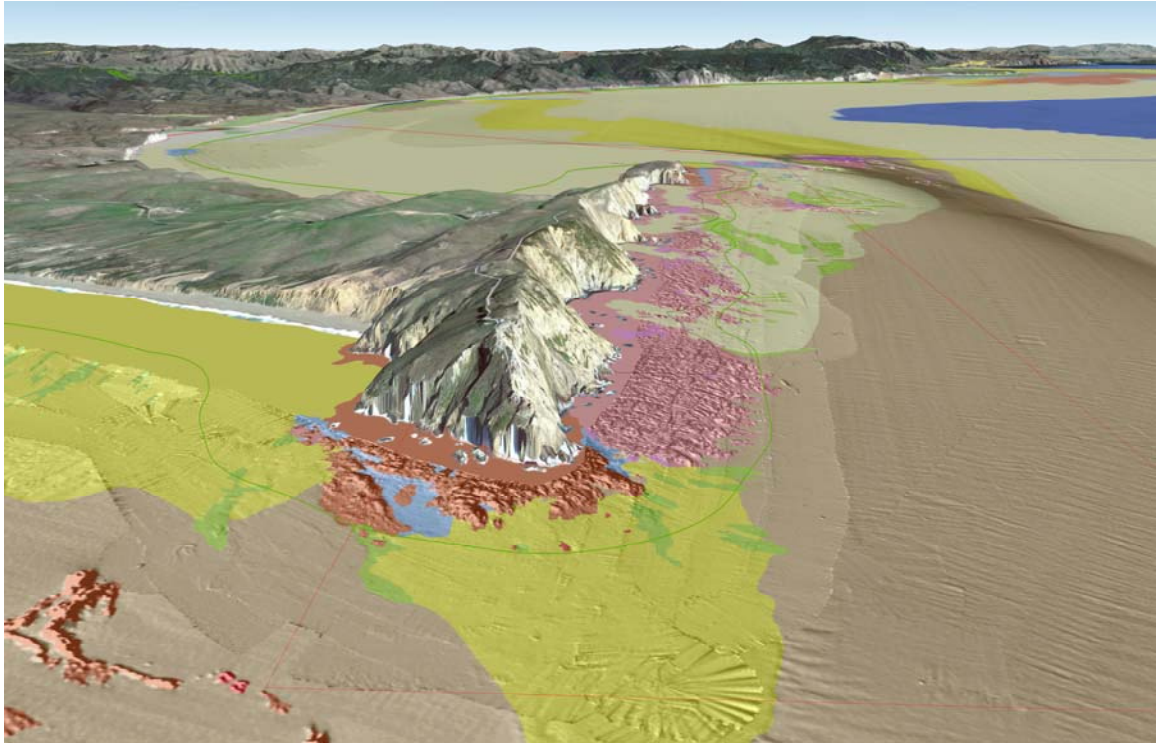

*Figure 7. Hard (brown and pink color) potential rockfish (*Sebastes *spp.) habitat off Point Reyes. Smooth, clean-looking areas close to shore are the "white zones" (data gaps) that have been filled through the interpretation of data other than the geophysical data sets used for mapping geology and habitats in deeper water, such as air photos and terrestrial LiDAR, and interpolation of land geology to the offshore. Stripping or waviness in smoother part of the image is artifact generated from role and other errors obtained during acquisition and not completely eliminated during data processing. The fan-shaped design at the lower center part of the image is the result of turns made by the acquisition vessel while data were being collected. Note landslide onshore in the western face of the Point Reyes Headland. View is looking east.*

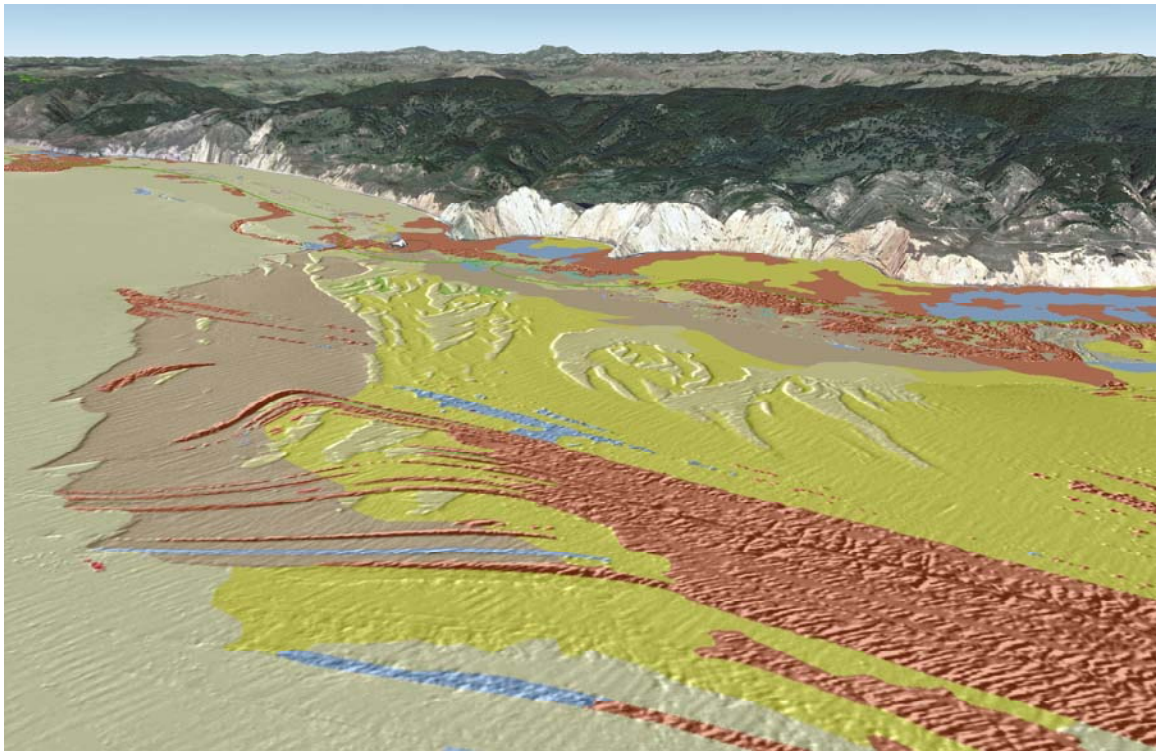

Figure 8. Example of the variety of marine benthic habitats north of Duxbury Reef where well bedded, differentially eroded Tertiary sedimentary rock exposures produce good rockfish habitats. Dynamic bedforms, such as soft mobile sediment (sand) sheets and dunes, offer good potential forage fish habitats (sand lance, *Ammodytes hexapterus*). *The nearshore zone shows areas of interpolation where MBES data do not exist. Striations (visible in foreground) are survey roll error artifacts. View looking east.*

6. Conclusions

Six 1:48,000 scale map sheets and one Perspective Views sheet of specific areas of interest were constructed for this project. These geologic and habitat map sheets represent the MBES bathymetric images and backscatter or acoustic intensity and side-scan sonar data sets used to construct the geologic and habitat map sheets. Habitat types are characterized as potential habitats that may represent actual habitats for a particular species or assemblage of organisms but biological information is needed to confirm the true habitat types. Thirty-nine distinct habitat types and 18 geologic units have been mapped. Of the potential habitat types mapped on the continental shelf 80.4% represents unconsolidated sediment substrate with 3.5% of this substrate type being a mixture of hard and soft substrate and the remaining 16.1% being hard substrate (10.8% sedimentary rock, and 5.3% granite; Fig. 9). In the estuaries the total potential habitat or substrate type consists of 99.7 % soft unconsolidated sediment and 0.3% hard substrate.

The PORE offshore area is a diverse and dynamic environment. Unlike Golden Gate National Recreational Area, the region is generally removed from urban and industrial

activity and inputs, with the exception of past and declining agricultural activities. Impacts to the ecology, including alteration of benthic habitats that may reduce the propagation and sustainability of demersal organisms and associated fisheries, are generally lacking. While terrestrial and wetland environments, which provide critical habitat for a multitude of fauna including birds, fishes, mammals and amphibians, have been well studied within the park, only a handful of habitat-related studies have been attempted in the deeper offshore areas of the park. One of the goals, therefore, was to identify potentially important benthic habitat types, especially for bottom fishes (e.g., rockfish and lingcod), and other recreationally important fisheries habitats that should be protected in order to sustain both the local ecology and economically important fisheries.

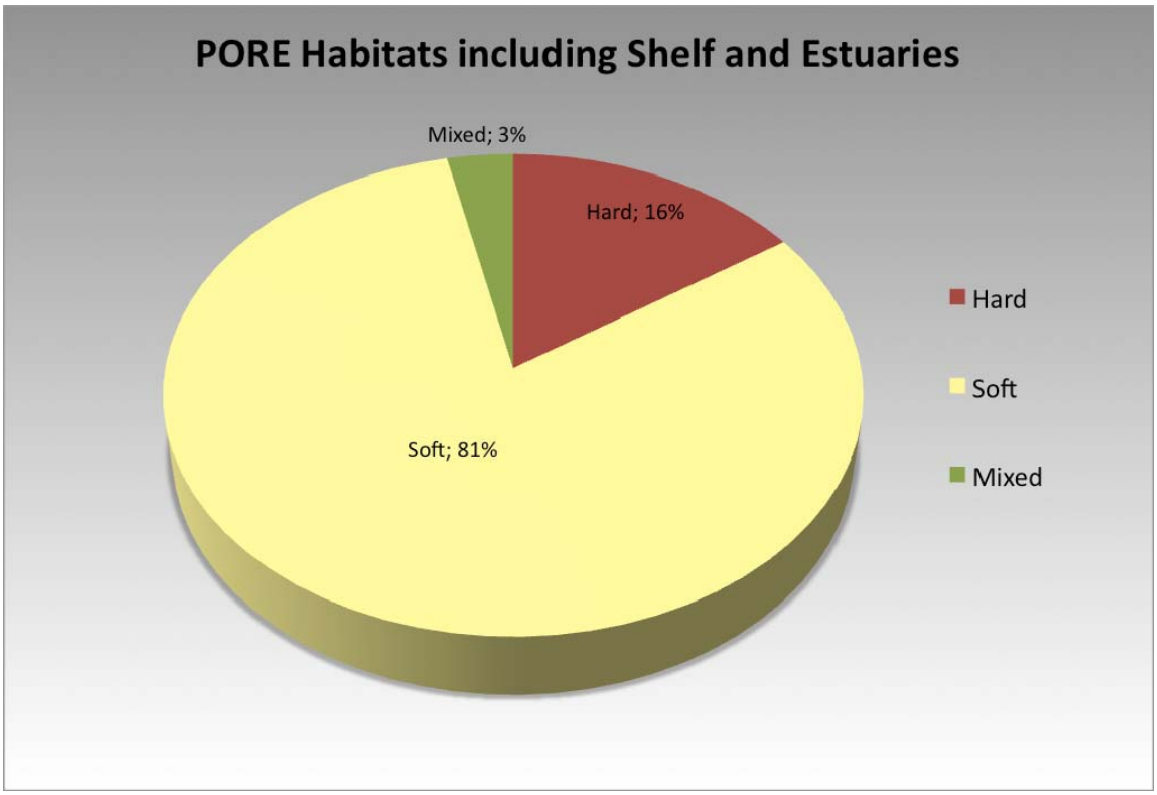

Figure 9. Pie chart of the percentage of potential habitat types mapped in PORE.

6.1. Sediment Distribution

PORE is an open-ocean park; its coast and nearshore areas are subjected to full, and sometimes severe, wave energy and strong longshore currents. However, the Point Reyes Headlands provides some protection from these natural oceanic conditions by providing shelter to Drakes Bay from northwest storm attacks. Based on the MBES bathymetric images it appears that significant erosion and transport of sediment occurs from Elephant Point south along Point Reyes Beach to Point Reyes where strong wave refraction around Point Reyes sweeps sediment around the point as dunes and mobile sand sheets (Fig. 5)

and along the headlands to Drakes Bay where the sediment accumulates (see Map Sheet 2). Strong bottom currents also appear to be transporting sediment in the form of dunes, mobile sand sheets and sediment waves along the nearshore area between Double Point and Palomarin Beach (see Map Sheet 2).

6.2. Fisheries Habitats

The maps show two basic hard rock seafloor exposures on the continental shelf that have the textural complexity (rugosity) to provide suitable habitat for adult rockfish and lingcod. The two habitat types are granite basement rocks and sedimentary bedrock. These potential habitats are concentrated along the western offshore mapped area with granite exposures in the northern part that extend offshore from the park (see Map Sheet 4 and Fig. 6). From Elephant Rock to Point Reyes the nearshore habitat is comprised of soft sand, but offshore of this area outside of the park's boundary, extensive hard deformed and differentially eroded bedrock are exposed. Thus, the entire stretch of offshore from north of Tomales Bluff to Point Reyes contains promising potential rockfish and lingcod habitat.

Granitic rocks are the predominant hard substrate found along the southern margin of Point Reyes Headland, within the park boundary, and this area is also a promising location for rockfish and lingcod habitat. These rock types extend offshore of the eastern point of the headlands where the exposures are evidently kept clean of sediment from strong bottom currents that sweep past the point into Drakes Bay.

Sandy habitats occur in the park around Drakes Bay to Santa Maria Beach (see Map Sheet 5), whereas hard differentially eroded sedimentary bedrock outcrops occur within the park south along the coast to Double Point (see Map Sheet 5 and Fig. 8). From Double Point to Bolinas Bay deformed and differentially eroded sedimentary bedrock is exposed along a significant part of the seafloor. These hard rock outcrops again provide promising potential rockfish habitat.

6.3 Foraging Habitats

Dynamic bedforms such as sand wave fields, mobile sand sheets and dunes may provide important foraging habitat to demersal and migratory fishes. Diet of juvenile lingcod in the San Juan Channel of the San Juan Islands region of Washington State was 100% of sand lance (Beaudreau, 2005). Greene et al. (2007) observed the presence of juvenile lingcod on the sand wave fields of the San Juan Channel, which led to an extensive study of the field. Continued study of this sand wave field indicates that sand lance may overwinter in the field. Salmon are believed to use dynamic bedforms as a foraging habitat, and even pursue sand lance into the sediment (Alan Fritzburg Personal Commun., 2010). Further observations suggest that perhaps the sand wave field is also a foraging habitat for juvenile lingcod and the source for much of its early feeding. Therefore, we conclude that forage fish (Pacific sand lance) may be using the dynamic bedforms in or near PORE for refuge and could be forage for lingcod, rockfish, salmon (*Oncorhynchus* spp.), and birds, similar to the feeding habitats observed in the San Juan Archipelago.

The Quaternary sand dunes and Pliocene sedimentary units exposed along Point Reyes Beach are "feeder bluffs" that provide sands and other material to the littoral drift and may provide the sediment critical to the maintenance of potential forage fish (sand lance) habitats. If sand lance use the dynamic bedforms in and around PORE, then the feeder bluffs are necessary to sustain the sediment supply that form the habitats.

The results of this work constitute the most comprehensive deep-water benthic habitat interpretation to date of the PORE offshore region and the adjacent continental shelf. The maps constructed and presented here should provide a good foundation for future ecologic, geologic and oceanographic studies.

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Appendix I
Data Source List

PORE Habitat Mapping Data List

Multibeam Bathymetry Grids

File Name: "cc2a01_06" & "cc207_11"
Description: Multibeam data, gridded to a 2 meter cellsize, with coverage from about 20 meters water depth out to the 3-mile limit. These two grids are mosaics created from 11 individual grids obtained from the CSUMB Seafloor Mapping Lab.
Source: Data were acquired, processed, archived, and distributed by the Seafloor Mapping Lab of California State University Monterey Bay. Online link: http://seafloor.csumb.edu/SFMLwebDATA_CSWMP.htm

File Names: "ptr_d1_1" and "ptr_d1_2rs"
Description: Bathymetry data, gridded to a 0.5 meter cellsize, covering nearshore areas around the Point Reyes Headlands from about 10-30 meters water depth. Data were collected with a GeoAcoustics Inc. 250 kHz GeoSwath multibeam SSS system. GeoSwath is an amplitude and phase measuring system, which acquires SSS and interferometric bathymetry data.
Source: The Center for Habitat Studies, Moss Landing Marine Laboratories. Chief Scientist, Mercedes D. Erdey-Heydorn

File Names: "ptr_d2_1", "ptr_d2_2" and "ptr_d2_3"
Description: Bathymetry data, gridded to a 0.5 meter cellsize, covering nearshore areas from about Pt. Resistance to Duxbury Reef in water depths of about 5-15 meters. Data were collected with a GeoAcoustics Inc. 250 kHz GeoSwath multibeam SSS system. GeoSwath is an amplitude and phase measuring system, which acquires SSS and interferometric bathymetry data.
Source: The Center for Habitat Studies, Moss Landing Marine Laboratories. Chief Scientist, Mercedes D. Erdey-Heydorn.

File Name: "drakes1m"
Description: Multibeam data, gridded to a 1 meter cellsize, covering a portion of Drakes Bay in water depths of about 5-20 meters.
Source: Eric Moore at the National Oceanographic and Atmospheric Administration (NOAA).

File Name: "CC_00_2mbathy"
Description: Multibeam data, gridded to a 2 meter cellsize, covering the southeast portion of the 1:48,000 map area.
Source: Data were acquired, processed, archived, and distributed by the Seafloor Mapping Lab of California State University Monterey Bay. Online link: http://seafloor.csumb.edu/SFMLwebDATA_NCCMP_P2A.htm

File Name: "tomales_4m
Description: Multibeam data, gridded to a 4 meter cellsize, covering much of Tomales Bay. This dataset is composed of data from three bathymetric surveys collected between November 2004 and August 2006
Source: USGS, online at: http://pubs.usgs.gov/of/2008/1237/

Other Bathymetry Data

File Name: "noaa_soundings_wgs84utm10.shp"
Description: Point shapefile of bathymetric soundings for the entire 1:48,000 map area.
Source: Obtained through NGDCs Hydrographic Survey Database which includes surveys by the U.S. National Ocean Service. Data link: http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html

File Name: "tbath5"
Description: Bathymetry grid interpolated from point soundings file **"**noaa_soundings_wgs84utm10.shp" with a cell size of 5 meters. Covers most of Tomales Bay.
Source: Point soundings used for interpolation were obtained through NGDCs Hydrographic Survey Database which includes surveys by the U.S. National Ocean Service. Data link: http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html

File Name: "ngdc25"
Description: Bathymetry grid with a cell size of 25 meters covering most of the seafloor within the 1:48,000 map area.
Source: National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS). Online link: http://www.ngdc.noaa.gov/mgg/coastal/coastal.html

File Name: "noaa15"
Description: Bathymetry grid interpolated from point soundings file **"**noaa_soundings_nad83utm10.shp" with a cell size of 15 meters. Covers most of the seafloor within the 1:48,000 map area.
Source: Point soundings used for interpolation were obtained through NGDCs Hydrographic Survey Database which includes surveys by the U.S. National Ocean Service. Data link: http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html

Backscatter and Side-Scan Sonar (SSS) Data

File Names: "a01_sss_1m_ss_trace_bp_arc" through "a11_sss_1m_ss_trace_bp_arc" and "b01_sss_1m_ss_trace_bp_arc" through "b03_sss_1m_ss_trace_bp_arc"
Description: Tiff images of backscatter collected concurrently and covering the same area as the bathymetry grids "cc2a01_06" & "cc207_11". Backscatter is represented by 255 levels of gray (8-bit) with a pixel size of 1 meter. Brighter shades represent high backscatter (generally harder seabed) while darker shades represent low backscatter (generally softer seabed).
Source: Data were acquired, processed, archived, and distributed by the Seafloor Mapping Lab of California State University Monterey Bay. Online link: http://seafloor.csumb.edu/SFMLwebDATA_CSWMP.htm

File Names: "ptr_ss_d1_1", "ptr_ss_d1_2", "ptr_ss_d2_1", & "ptr_ss_d2_2", & "ptr_ss_d2_3"
Description: SSS grids, with cellsize of 0.5 meters, collected concurrently and covering the same area as the bathymetry grids **"**ptr_ d1_1", "ptr_ d1_2", "ptr_ d2_1", "ptr_ d2_2", & "ptr_ d2_3". Data were collected with a GeoAcoustics Inc. 250 kHz GeoSwath multibeam SSS system. GeoSwath is an amplitude and phase measuring system, which acquires SSS and interferometric bathymetry data.
Source: The Center for Habitat Studies, Moss Landing Marine Laboratories. Chief Scientist, Mercedes D. Erdey-Heydorn

File Name: "tomales_bs2m"
Description: The Tomales Bay backscatter amplitude grid (cellsize = 2m) is composed of data from two interferometric sidescansonar surveys collected in November 2004 and November 2005 (USGS activities F-1-04-TB, F-2-05-TB). Data were collected concurrently and covering the same area as the bathymetry grid **"**tomales_4m".
Source: USGS, online at: http://pubs.usgs.gov/of/2008/1237/

File Name: "Drakes_Bay_mosaic"
Description: Backscatter image, with cellsize of 2 meters, collected concurrently and covering the same area as the bathymetry grid **"**drakes1m".
Source: Eric Moore at the National Oceanographic and Atmospheric Administration (NOAA).

Ground Truth Data

File Name: "CBI_Segments.shp"
Description: Polyline shapefile - Coastal Biological Inventory of shoreline from Tomales Point south to Pillar Point. Does not include Tomales Bay, Drakes Estero, Bolinas Lagoon or San Francisco Bay.
Source: Pacific Coast Science and Learning Center, 2007.

File Name: "Trackline2009.shp"
Description: Polyline shapefile of ROV tracklines collected by Pacific States Marine Fisheries Commission in 2009.
Source: Andy Lauerman at Pacific States Marine Fisheries Commission.

File Name: "Anima_08_grabs.shp"
Description: Point shapefile of grab samples within Tomales Bay. Table contains a brief description of each sample. Sediment samples were collected by grab sampler from aboard a 21-foot Boston whaler August 15 and 16, 2005.
Source: USGS, online at: http://pubs.usgs.gov/of/2008/1237/

File Name: "Pac_clc.shp"
Description: Calculated seabed data for the continental margin of the U.S. Pacific Coast (California, Oregon, Washington) from usSEABED
Source: Reid, Jane A. , Reid, Jamey M. , Jenkins, Chris J. , Zimmermann, Mark, Williams, S. Jeffress , and Field, Michael E. , 2006. Calculated seabed data for the continental margin of the U.S. Pacific Coast (California, Oregon, Washington) from usSEABED. U.S. Geological Survey.

File Name: "f307nc_finalobs.shp"
Description: Point shapefile containing visual observations of seafloor character (benthic habitat), flora and fauna from video obtained with a towed camera sled.
Source: Data obtained during USGS cruise ID F-3-07-NC. Brian Edwards, Pete Dartnell, Eleyne Phillips. See: http://walrus.wr.usgs.gov/infobank/f/f307nc/html/f-3-07-nc.meta.html

File Name: "l908nc_finalobs.shp"
Description: Point shapefile containing visual observations of seafloor character (benthic habitat), flora and fauna from video obtained with a towed camera sled.
Source: Data obtained during USGS cruise ID L-9-08-NC. Brian Edwards, Pete Dartnell, Eleyne Phillips. See: http://walrus.wr.usgs.gov/infobank/l/l908nc/html/l-9-08-nc.meta.html

File Name: "BIO_NCCSR_Kelp2009.shp"
Description: Polygon shapefile of kelp canopy and kelp subsurface distribution. The dataset is used to assess the extent of kelp resources along the North Central California coast (Pigeon Point to Alder Creek
Source: The Resources Legacy Fund Foundation (contract), the Marine Protected Areas Monitoring Enterprise (coordination), Ocean Imaging (data collection and processing), The California Department of Fish and Game (database management),

Elevation and Landcover Data

File Name: "ned8"
Description: **1**/3 arc second NED data projected to UTM WGS84 Zone10 and re-sampled to 8 meters. The National Elevation Dataset (NED) is the primary elevation data product produced and distributed by the USGS. The NED provides the best available public domain raster elevation data of the conterminous United States, Alaska, Hawaii, and territorial islands in a seamless format.
Source: U.S. Geological Survey (USGS). Obtained from USGG, online at http://seamless.usgs.gov

File Name: "lid3m_1998"
Description: LIDAR elevation data with 3 meter cellsize. Covers a strip of coastal area from Limantour beach south to about Stinson Beach. Data were collected in 1998.
Source: Airborne Topographic Mapper LIDAR data were collected in partnership with the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, the NASA Wallops Flight Facility, the U. S. Geological Survey (USGS) Center for Coastal and Regional Marine Geology, and the NOAA Aircraft Operations Center.

File Name: "prns_lid2m"
Description: LIDAR elevation data with 2 meter cellsize. Covers a strip of coastal area from Limantour beach north to Bodega Bay and includes the shorelines of Drakes and Tomales Bays.
Source: This Airborne Topographic Mapper LIDAR data set was collected in partnership with the NASA Wallops Flight Facility, and the U. S. Geological Survey (USGS) Center for Coastal and Regional Marine Geology.

File Name: "landcover.tif"
Description: **Tiff** image of landcover classifications at a 30 meter pixel resolution. The National Land Cover Database 2001 land cover layer for mapping zone 04 was produced through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium.
Source: Obtained from USGG, online at http://seamless.usgs.gov. References: Homer, C., C. Huang, L. Yang, B. Wylie and M. Coan, 2004. Development of a 2001 national land cover database for the United States. Photogrammetric Engineering and Remote Sensing Vol.70,No.7,pp 829-840 or online at www.mrlc.gov/publications.The USGS acknowledges the support of NOAA and Earth Satellite Corp in development of data in this zone.

Orthoimagery

File Name: "Orthophotos.lyr"
Description: A layer file linked to a group of 65 orthophoto tiles with coverage of the entire PRNS. Each tile is 12000 x 8000 pixels with a pixel resolution of 1 foot.
Source: Marin Map - A Geographic Information System For Marin County, CA. Image download at: http://mmgis.marinmap.org/OrthoGrid/viewer.htm

Ancillary Data

File Name: "MPA_CA_Existing.shp"
Description: Polygon shapefile. These data include all of California's marine protected areas (MPAs) as of July 2010.
Source: California Department of Fish and Game, Marine Region GIS lab. ftp://ftp.dfg.ca.gov/R7_MR/MANAGEMENT/MPA/

File Name: "pore_trails.shp"
Description: Polyline shapefile of hiking and biking trails within the Point Reyes National Seashore and Golden Gate National Recreation Area boundaries.
Source: National Park Service

File Name: "Points_of_Interest.shp"
Description: Locations of interest within and nearby the Point Reyes National Seashore. Points were digitized from the NPS map entitled "map_park.pdf".
Source: Center for Habitat Studies. The source map, "map_park.pdf" was obtained online from: http://www.nps.gov/pore/planyourvisit/maps.htm

File Name: "48k_map_bounds.shp"
Description: boundry polygon outlining area of the 1:48,000 scale map sheets produced as part of the Marine *Benthic Habitat Mapping of Point Reyes National Seashore* project.
Source: Generated by the Center for Habitat Studies.

File Name: "data_footprints.shp"
Description: Polygon shapefile outlining extents of data used for benthic habitat and geology interpretations.
Source: Generated by the Center for Habitat Studies.

File Name: "nps_boundary.shp"
Description: Polygon shapefile National Park boundaries.
Source: National Park Service. Online linkage: http://nrdata.nps.gov/programs/lands/nps_boundary.shp

File Name: "coastutm_z10.shp"
Description: Polyline shapefile of the California coastline from the Oregon border to the Mexico border.
Source: Digitized from 7.5' USGS quadrangles. Teale Data Center, US Geological Survey (Various years).

File Name: "ESRI_detailed_streets_clip.shp"
Description: Polyline shapefile of road network clipped to area of the 1:48,000 scale map sheet.
Source: From Tele Atlas North America, Inc., ESRI

File Name: "PTR_Lakes.shp"
Description: Polygon of water bodies, clipped to area of the 1:48,000 scale map sheet.
Source: U.S. Geological Survey in cooperation with U.S. Environmental Protection Agency, ESRI

File Name: "PTR_Lakes.shp"
Description: Polygon of water bodies, clipped to area of the 1:48,000 scale map sheet.
Source: U.S. Geological Survey in cooperation with U.S. Environmental Protection Agency, ESRI

Benthic Habitats

File Name: "PtReyes_offshore_habitat.shp"
Description: Polygon shapefile of potential marine benthic habitats using the CMECS/Greene classification standard. Coverage extends out to the 3-mile limit.
Source: Generated by the Center for Habitat Studies.

File Name: "PointReyes_WhiteZone_Habitats.shp" **Description**: Polygon shapefile of potential marine benthic habitats using the CMECS/Greene classification standard. Covers the "white zone" area where no high resolution data exists, between the shoreline and the offshore habitat coverage.
Source: Generated by the Center for Habitat Studies.

Offshore Geology

File Name: "PtReyes_offshore_geology.shp"
Description: Polygon shapefile of offshore geologic units out to the 3-mile limit, where high resolution seafloor data exists.
Source: Generated by the Center for Habitat Studies.

File Name: "PointReyes_WhiteZone_Geology.shp"
Description: Polygon shapefile of offshore geologic units. Covers the "white zone" area where no high resolution data exists, between the shoreline and the offshore habitat coverage.
Source: Generated by the Center for Habitat Studies.

File Name: "OffshoreGeology_GGNRA.shp"
Description: Polygon shapefile of offshore geologic units out to the 3-mile limit, where high resolution seafloor data exists, covering the southeast corner of the map area.
Source: Generated by the Center for Habitat Studies.

File Name: "PRNS_offshore geo-structure.shp"
Description: Polyline shapefile of offshore faultlines.
Source: Generated by the Center for Habitat Studies. Supplimentary information: Ryan, H. F., Parsons, T., and Sliter, R. W., 2008, Vertical tectonic deformation associated with the San Andreas fault zone offshore of San Francisco, California, Tectonophysics 457, pp. 209-223, doi10.1016/j.tecto.2008.06.011

Terrestrial Geology

File Name: "Marin_geology_utm10.shp"
Description: Polygon shapefile of Geologic units clipped to 1:48,000 map area
Source: Conpiled from four USGS publications and 2004 topographic mapping. Publications are OFR97-456 (2007), MF-2337 (2000), MF-2402 (2005), and SIM-2956 (2007).

File Name: "pr-str-arc_utm10.shp"
Description: Polyline shapefile of fold axes.
Source: Clark, J.C., and Brabb, E.E., 1997, Geology of Point Reyes National Seashore and vicinity, California: a digital database: U.S. Geological Survey Open File Report OF 97-456 Online linkage: http://pubs.usgs.gov/of/1997/of97-456/

File Name: "pr-oil_point.shp"
Description: Point shapefile of locations of abandoned exploratory wells.
Source: Clark, J.C., and Brabb, E.E., 1997, Geology of Point Reyes National Seashore and vicinity, California: a digital database: U.S. Geological Survey Open File Report OF 97-456 Online linkage: http://pubs.usgs.gov/of/1997/of97-456/

File Name: "pr-arrows_utm10.shp"
Description: Polyline shapefile indicating general direction of landslide movement.
Source: Clark, J.C., and Brabb, E.E., 1997, Geology of Point Reyes National Seashore and vicinity, California: a digital database: U.S. Geological Survey Open File Report OF 97-456 Online linkage: http://pubs.usgs.gov/of/1997/of97-456/

File Name: "pr-str-point_utm10.shp"
Description: Point shapefile of bedding attitude.
Source: Clark, J.C., and Brabb, E.E., 1997, Geology of Point Reyes National Seashore and vicinity, California: a digital database: U.S. Geological Survey Open File Report OF 97-456 Online linkage: http://pubs.usgs.gov/of/1997/of97-456/

Appendix II
Habitat Mapping Code
(Modified after Greene et al., 2007)

Key to Habitat Code

System – Marine
Subsystem - Tropical

An attribute code was written to easily distinguish each habitat type and to facilitate ease of use and queries in GIS (e.g., ArcGIS). This code is based on the deep-water habitat characterization scheme developed by Greene et al. (1999) and modified for use in mapping habitats offshore of California (Greene et al., 2005, 2007) and here has been expanded to address habitats in a Tropical environment (0-1000 m water depth and 0-23° North and South Latitude). The code is designed so that the first character in the code, a capital letter, indicates one of nine Megahabitat types. These general Megahabitat types with suggested depth ranges in parentheses[2] are as follows:

A = Aprons, continental rise, deep fans and bajadas (3000-4000 m)
B = Basin floors, borderland types (floors at 1000-2500 m)
D = Demarcation, shelf edge or shelf break (100-200 m)
E = Estuary, (0-100 m)
F = Flanks, continental slope, basin/island flanks (200-3000 m)
I = Inland seas, fiords, and narrow inlets or passages (0-200 m)
M = Submarine mesa or plateau (200-1000 m)
P = Plains, abyssal (4000-6000+ m)
R = Ridges and seamounts (crests at 200-2500 m)
S = Shelf, continental and island shelves (0-200 m)
T = Trench, represents subduction, or paleo-subduction zones (3000-7000 m)
Z= Zone of fractures (3000-5000 m) or fracture zones associated with spreading ridges

The second character in the code, a lower case letter, indicates bottom induration (hardness) and consists of the following:

h = hard bottom (e.g., rock outcrop or sediment pavement)
m = mixed hard and soft bottom (e.g., local sediment cover of bedrock)
s = soft bottom, sediment cover
<u>Sediment types</u> (for above indurations) - Use parentheses.

[2] Depths found in parentheses are estimations and can be changed to fit depth ranges known to occur for the mapping project at hand.

(b) = boulder
(c) = cobble
(p) = pebble
(g) = gravel
(s) = sand
(m) = mud, silt, clay
(h) = halimeda sediment, carbonate

When inferred, use question mark; i.e., (m?). This part of the code is not always used so is not considered as a character in the code.

The third character in the code, another lower case letter, not always used, indicates the Meso- or Macrohabitat type (based on scale). These types consist of the following:

a = atoll
b = beach, relic (submerged) or shoreline
c = canyon
  c(b) = bar within thalweg
  c(c) = curve or meander within the thalweg
  c(f) = fall or chute within the thalweg
  c(h) = canyon head
  c(m) = canyon mouth
  c(t) = thalweg
  c(w) = canyon wall
d = deformed, tilted and folded bedrock, overhangs
e = exposure, bedrock
f = flats, floors
g = gully, channel
h = hole, depression
i = ice-formed feature or deposit, moraine, drop-stone depression
k = karst, solution pit, sink
l = landslide, mass movement, rubble
m = mound; includes linear ridges
n = enclosed waters, lagoon
o = overbank deposit (levee)
p = pinnacle, cone (Note: Pinnacles are often difficult to distinguish from boulders. Therefore, these features may be used in conjunction [as (b)/p] to designate the meso/macrohabitat)
q = bay, embayment, bights, sounds
r = rill (subterranean winnowing of sediments forming linear depressions on surface
s = scarp, cliff, fault or slump scar
t = terrace

u = underwater tidal lands, tidepools
v = vegetative sediment or rock (grass or algae covered)
  v(a) = algae
  v(e) = eelgrass
w = dynamic bedforms
  w(d) = sediment dunes (10s of m in amplitude, 100s m in period)
  w(s) = sediment sheet
  w(w) = sediment waves (10 cm to <m amplitude, 10s m in period) and dunes

x = seamount
  x(b) = seamount base
  x(c) = seamount crest, top
  x/f = flat-topped seamount, guyot
y = delta, fan
z = zooxanthellae hosting structure, carbonate reef
  z(br) = barrier reef
  z(fr) = fringing reef
  z(h/b) = head, bommie
  z(pr) = patch reef
  z(rr) = rear or back reef
  z (rf) = reef flat
  z(rc) = reef crest
  z(fr) = fore reef

The fourth character in the code, preceded by an underline (i.e., _a), is a modifier that describes the texture, bedform, biology or rock type and consists of the following:

_a = anthropogenic (artificial reef/breakwall/shipwreck/disturbances)
  (a-c) = cable
  (a-dd) = dredge disturbances
  (a-dg) = dredge grooves or channels
  (a-dp) = dredge potholes
  (a-dm) = dredge mounds (disposal)
  (a-f) = ferry or other vessel prop wash scour or scar
  (a-td) = trawl disturbances
  (a-g) = groins, jetties, rip-rap
  (a-m) = marina, harbor
  (a-p) = pipelines
  (a-s) = supports; dock pilings, dolphins, platform legs/pipes
  (a-w)= wreck, ship, barge or plane
_b = bimodal (conglomeratic, mixed [includes gravel, cobbles and pebbles])
_c = consolidated sediment (includes claystone, mudstone, siltstone, sandstone, breccia, or conglomerate)
_d = differentially eroded
_e = effusive pit, pockmark
_f = fracture, joint; faulted

_g = granite, intrusive
_h = hummocky, irregular relief
_i = interface, lithologic contact
_k = kelp
_l = limestone or carbonate rock or structure
    _l(a) = alive reef
    _l(d) = dead reef
    _l(l) = linear reef
    _l(s-g) = spur and groove
    _l(p) = patch reef
    _l(pr-i) = individual patch reef
    _l(pr-a) = aggregated patch reef
    _l(r) = reef rubble
_m = massive sedimentary bedrock
_o = outwash
_p = pavement
_r = ripples (>10 cm in amplitude)
_s = scour (current or ice, direction noted)
_t = tar flow or asphalt
_u = unconsolidated sediment
_v = volcanic rock, tuff
_w = wall

Seafloor Slope - Use category numbers, which is the fifth character in the code. Typically calculated for survey area from x-y-z multibeam data.

1 Flat (0-5º)[3]
2 Sloping (5-30º)
3 Steeply Sloping (30-45º)
4 Vertical (45-90º)
5 Overhang (>90º)
6 Unknown

Seafloor Rugosity - Use category letters (in caps), the sixth character in the code. Typically calculated for survey area from gridded x-y-z multibeam data using neighborhood statistics and reported as the ratio of surface area to planar (flat) area for a particular grid cell.

A Very Low Rugosity (1.00 to 1.25)
B Low Rugosity (1.25 to 1.50)
C Moderate Rugosity (1.50 to 1.75)
D High Rugosity (1.75 to 2.00)
E Very High Rugosity (> 2.00)

[3] Numbers in parentheses are suggestions only and can be tailored to meet objectives of the habitat mapping exercise at hand.

An example of how this code for remotely sensed data can be used is given below:

Ssc_u4 = Canyon head indenting shelf with smooth, soft, gentle-sloping sedimentary walls locally croping out as steep (near vertical) scarps (10-100 m).

Ssf_u = Flat to gently sloping shelf with soft, unconsolidated sediment (10-150 m).

Fhe_m/cC = Continental slope with hard sedimentary (sandstone) bedrock locally cropping out and smooth to moderately irregular relief (<1-3 m high): m means exposures often covered with sediment (200-2500 m).

Shz/t_l/h1D = Reef terrace at shelf depth, carbonate, flat with hummocky (high rugosity) surface

Geologic Unit – When possible, the associated geologic unit is identified for each habitat type and follows the habitat designation in parentheses. Examples given below:

Shp_d1D(Q/R) - Continental shelf megahabitat; flat, highly complex hard seafloor with pinnacles differentially eroded. Geologic unit = Quaternary/Recent.

Fhd_d2C (Tmm) - Continental slope megahabitat; sloping hard seafloor of deformed (tilted, faulted, folded), differentially eroded bedrock exposure forming overhangs and caves. Geologic unit = Tertiary Miocene Monterey Formation.