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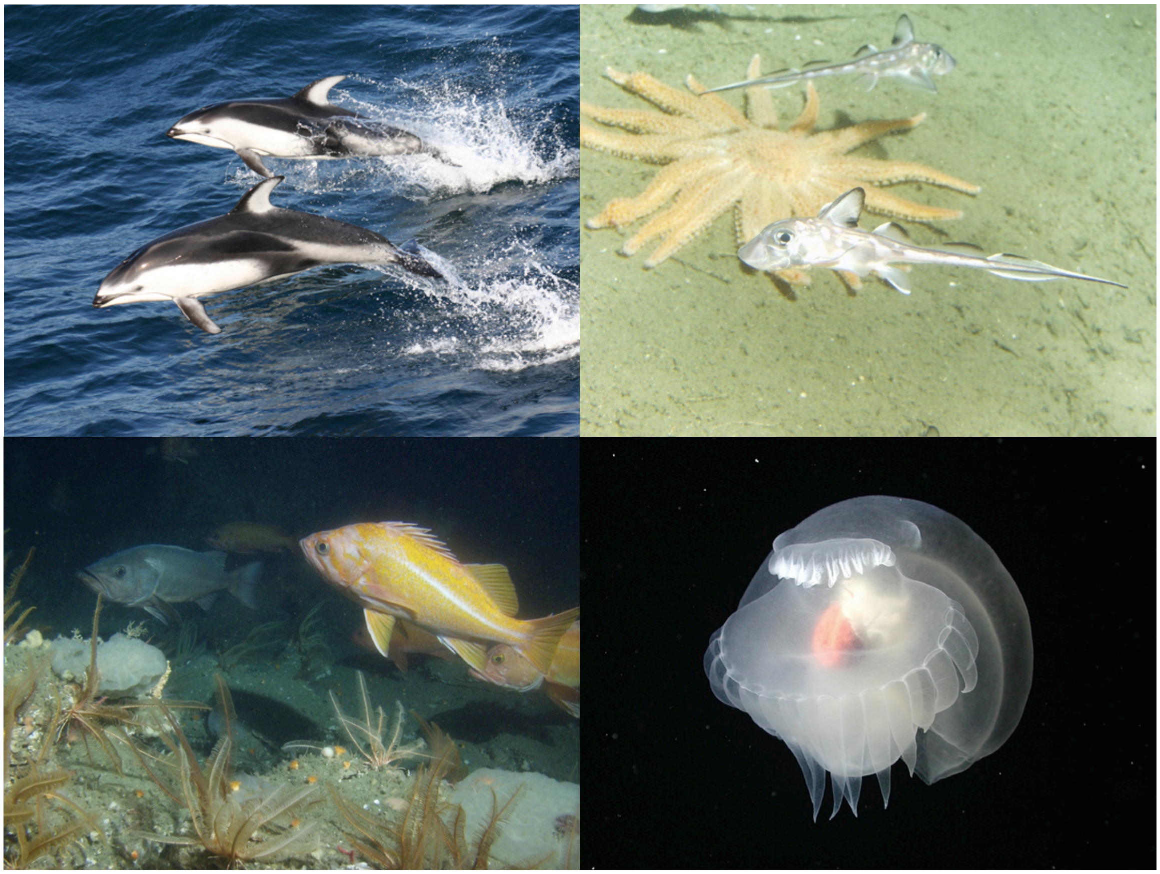

The Natural Resources of Monterey Bay National Marine Sanctuary:

A Focus on Federal Waters

Final Report
June 2013

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
Office of National Marine Sanctuaries

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Jennifer A. Brown, Erica Burton, Sophie De Beukelaer

Monterey Bay National Marine Sanctuary

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Cover

Top Left: Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), Chad King/MBNMS
Top Right: Spotted ratfish (*Hydrolagus colliei*) and sun star (*Rathbunaster californicus*), Jean deMarignac/MBNMS
Bottom Left: Canary rockfish (*Sebastes pinniger*), bocaccio (*S. paucispinis*), yelloweye rockfish (*S. ruberrimus*), feather stars (*Florometra serratissima*) and sponges, Rick Starr/MBNMS
Bottom Right: "Mystery Mollusk" (Order Nudibranchia), NOAA/MBARI

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Abstract

This natural resources assessment synthesizes the current scientific knowledge of the physical and biological resources in the offshore habitats of Monterey Bay National Marine Sanctuary (MBNMS). The main body of this report is organized into sections by offshore habitat category. Benthic habitats categories were defined by substrate type (hard and soft) and depth: shelf I (30-100 m), shelf II (100-200 m), slope (200-3,000 m), and rise (>3,000 m). Additional offshore habitat categories included in this report are open ocean, submarine canyon, seamount, oxygen minimum zone, chemosynthetic biological communities, and macrophyte detritus. For each of these habitat categories, information was compiled on topics spanning many levels of ecological organization (e.g., population, species, community) and various ecological processes (e.g., productivity, dispersal). Information sources included primary literature, unpublished data, and expert interviews. The purpose of this document is to identify sources of regional information, and describe natural resources and processes in federal waters of Monterey Bay National Marine Sanctuary .

Key Words

Monterey Bay National Marine Sanctuary, natural resources, site characterization, continental shelf, continental slope, continental rise, open water, submarine canyon, seamount, oxygen minimum zone, plankton, algae, invertebrates, fishes, seabirds, marine mammals, sea turtles, species diversity, species richness, species composition, sensitive species

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Introduction

Background

Monterey Bay National Marine Sanctuary (MBNMS) is one of 13 national marine sanctuaries in U.S. waters. The National Marine Sanctuary System is mandated to "maintain for future generations the habitat and ecological services of the natural assemblages of living resources that inhabit these areas."[1] In order to accomplish this mandate for MBNMS, we need a thorough understanding of the natural resources occurring inside the sanctuary's boundaries.

The "Monterey Bay National Marine Sanctuary Site Characterization", completed in 1996, provided a summary of the existing information on the sanctuary's physical and biological features as well as human influences (Guerrero and Kvitek 1996). The site characterization provided the most current information on the status of MBNMS natural resources.

With more than 30 education and marine research institutions located in close proximity to the sanctuary, a substantial amount of new information has been collected on the status of natural resources in the sanctuary since the release of the site characterization. However, for that information to be used effectively in the management of sanctuary resources, it must be collected and synthesized. This natural resources assessment, which is focused on the habitats and resources in offshore waters, provides an updated compilation of scientific knowledge of the physical and biological resources in the offshore portions of the sanctuary. This report combines information from the site characterization with more recent studies to provide a more current and detailed understanding of offshore resources.

There are several reasons for the focus on offshore resources. First, there has already been a significant effort, led by the state of California as part of the California State Marine Life Protection Act process, to understand, protect, and monitor marine resources within state waters (< 3 nautical miles from shore). Second, improvements in sampling techniques and technologies, such as submersibles, satellites, and animal tags, have facilitated exploration and monitoring in the more remote portions of MBNMS. Third, these evolving technologies also change the landscape of current and potential human uses of sanctuary resources, including submerged cables, offshore aquaculture, and green energy development. An updated and expanded understanding of the physical and biological resources in the offshore habitats is critical to managing these resources in response to ever changing human influences.

MBNMS and Defined Study Area

Monterey Bay National Marine Sanctuary was established in 1992 by the Office of National Marine Sanctuaries. The sanctuary extends along the coast from Rocky Point (Marin County) to Cambria Rock (San Luis Obispo County), encompassing nearly 450 km of shoreline (Figure 1). As originally designated in 1992, MBNMS encompassed 13,780 km^2 of ocean, extended 91.5 km offshore at its widest point, and reached a depth of 3,250 m at its deepest point. On March 9, 2009, MBNMS was expanded by 2,007 km^2 to include the Davidson Seamount Management Zone (DSMZ). Davidson Seamount is one of the largest known underwater mountains in U.S.

[1] Title 16 United States Code, Chapter 32, §1431(a)(4)(C)

coastal waters; it is 2,280 m tall, 42 km long and 13 km wide. The shallowest point is 1,250 m below the ocean's surface and the deepest part of the DSMZ is 3,875 m.

The northern portion of MBNMS, extending along the coast of San Mateo and Santa Cruz Counties, consists of long stretches of sandstone cliffs with a few small beaches and estuaries created by coastal streams. This section of the sanctuary has a relatively wide and shallow continental shelf bisected by four submarine canyons: Pioneer, Ascension, Año Nuevo, and Cabrillo Canyons (Figure 2). Due to the broad continental shelf, the heads of these submarine canyons are located far from shore.

The central portion of MBNMS is dominated by Monterey Bay, which extends between Point Santa Cruz to the north and a prominent granite headland, Point Pinos, to the south. Monterey Bay covers an area of about 550 km^2. The northern coastline of Monterey Bay consists of sand bluffs, mudstone terraces, rocky intertidal benches, sand beaches, and cliffs. Two major rivers, the San Lorenzo and Pajaro, enter Monterey Bay along its north shore. Elkhorn Slough, the only large estuary in MBNMS, connects to the ocean at Moss Landing. The Salinas River, which is the major drainage system for the extensive Salinas Valley watershed, enters Monterey Bay to the south of Elkhorn Slough. Sandy beaches and dunes characterize the coastline extending between Moss Landing and the granite headlands of the Monterey peninsula. The broad, shallow continental shelf found in Monterey Bay is bisected by Monterey Canyon, the largest submarine canyon in the sanctuary. This canyon extends from the shore near Moss Landing to a depth of over 3,200 m. There are two main branches of Monterey Canyon: Soquel Canyon to the north and Carmel Canyon to the south (Figure 2).

South of the Monterey Peninsula, are Carmel Bay and the Big Sur coast. Big Sur is characterized by steep cliffs and rocky headlands interspersed with small pocket beaches. The watersheds of the Santa Lucia Range drain to the ocean through many streams and creeks that cut the steep western face of the mountain range. This steep topography continues below the ocean surface, resulting in a relatively narrow continental shelf incised by many submarine canyons, including Sur, Partington, and Lucia Canyons.

The Davidson Seamount is a pristine, volcanic undersea mountain habitat 129 km to the southwest of Monterey and 121 km west of San Simeon. The vertical nature and rocky substrate on the seamount creates habitat that is vastly different from the surrounding soft-sediments on the seafloor. The seamount hosts large coral forests, vast sponge fields, crabs, deep-sea fishes, shrimp, basket stars, and large numbers of rare and unidentified benthic species.

The study area for this natural resources assessment includes the portions of MBNMS to the south of Pigeon Point (San Mateo County) and to the west of the state waters boundary, including the DSMZ (hereafter referred to as the "federal study area"; Figure 1). Habitats and ecosystems that only occur in state waters (e.g., estuaries, intertidal zone, nearshore sandy seafloor) are not considered here.

Methods

The purpose of this natural resources assessment is to identify and describe the biological resources and ecological processes in the offshore habitats of the federal study area. A benthic habitat was defined as encompassing the seafloor and associated benthic and benthopelagic fauna. Benthic fauna include the epifauna (active, crawling, or attached organisms living on the surface of the seafloor) and infauna (organisms living buried in the sediments). Benthopelagic fauna are organisms swimming or drifting in the waters immediately over the seafloor.

Primary benthic habitats were identified according to substrate type and depth zone. The two major substrate types, soft bottom and hard bottom, were selected because very different biological communities are associated with each and coarse-scale substrate data are available for the entire MBNMS. Five benthic depth zones were identified (based on Airamé et al. 2003, Allen 2006, and Greene et al. 1999):

- Nearshore: 0-30 m
- Shelf I: 30-100 m
- Shelf II: 100-200 m
- Slope: 200-3,000 m
- Rise: >3,000 m

Figure 1 shows the spatial distribution of the primary benthic habitats in MBNMS and their overlap with the federal study area. Table 2 provides the area (km^2) in each primary benthic habitat and shows the percentage of the entire MBNMS and the federal study area in each habitat. The nearshore depth zone does not occur in the federal study area so it was excluded from this natural resources assessment.

The open water habitat was identified as an additional primary habitat. The open water habitat encompasses the entire water column, from the surface to just above the seafloor. Fauna in the open water habitat includes nektonic (strong swimmers) and planktonic (weak swimmers and drifters) organisms that rarely or never interact with benthic habitats.

In addition to the primary habitats, we identified features in the offshore waters of MBNMS that modify the biological communities and ecological processes typically associated with a given habitat. These features, hereafter referred to as secondary habitats, are:

- Submarine Canyon
- Seamount
- Oxygen Minimum Zone (OMZ)
- Chemosynthetic Biological Communities (CBCs)
- Macrophyte Detritus

Submarine canyons and seamounts are large geological features with substantially different topography than the surrounding shelf, slope and rise habitats. The spatial distribution of submarine canyon and seamount habitats are shown in Figure 2 and Figure 3, respectively. The oxygen minimum zone - a layer of the water column with reduced levels of dissolved oxygen - is an oceanographic feature that strongly influences the distribution and abundance of fauna where it intersects with the seafloor (Figure 4) and the water column (Figure 5). Table 2 provides the area (km^2) of seafloor (in MBNMS and in the federal study area) covered by submarine canyon, seamount, and oxygen minimum zone habitats. Chemosynthetic biological communities (Figure 6) and macrophyte detritus are features that provide primary production and biogenic structure to habitats with little to no other sources of energy and physical structure.

The main focus of the literature review for the secondary habitats was to identify the biological communities and ecological processes associated with these features and to describe how these features modify the processes and communities typically associated with a given depth and substrate type (i.e., primary habitats).

Literature Review and Data Gathering

In order to identify and describe the biological resources and ecological processes in the offshore habitats of the federal study area, we identified search topics spanning many levels of ecological organization (e.g., population, species, community) and various ecological processes (e.g., productivity, dispersal). The search topics were grouped under four themes: habitat function, habitat structure, movement and dispersal, and species of special interest (Table 1). These search topics were the target of information gathering efforts for each primary and secondary habitat.

The habitat information presented in this report was compiled in two phases. The first phase, which occurred from March-August 2006, consisted of a review of published papers and, to the extent that we could find them, unpublished reports and unpublished data through 2005. Research studies conducted in MBNMS (Figure 1) were the primary focus of the literature review and data gathering effort. However, if little to no information was found on a specific topic in the sanctuary, we broadened the search to include studies conducted along the California coast between Point Arena and Point Conception. When necessary, we further expanded our search to studies along western North America.

Information was gathered using library and internet resources, as well as personal communication with regional scientists. To search for information in the published literature, two electronic databases were accessed: Aquatic Sciences and Fisheries Abstracts (ASFA; 1971-2005) and BIOSIS Previews (1969-2005). In addition, broad searches on the internet were performed using web-based search engines (e.g., Google, Google Scholar). Appendix I provides a catalogue of the research studies used in this natural resources assessment. For each study, the following information was included in the appendix: timing of the study, location of the study, habitat category, and sampling method. Appendix VI lists regional scientist that provided personal communication including published studies, technical reports, and unpublished reports and data.

Relevant geo-referenced data layers were requested or constructed and assimilated in Geographical Information Systems (GIS). We focused on identifying and gathering the most complete, up-to-date, and reliable spatial data from authoritative sources that would help illustrate the spatial distribution of geological, oceanographic, and biological resources in offshore habitats. Appendix II provides a catalogue of the GIS data layers used in this natural resources assessment. For each data layer, the following information was included in the appendix: figure number, data type, data developer, a description of the how the data layer was developed and how it should be used, and a website where data can be downloaded (if available).

The second phase (2006-July 2012) consisted of a targeted updating of geo-referenced data layers and inclusion of more recent studies for specific topics related to on-going resource management concerns and actions. New information was added to the habitat summaries and many of the GIS data layers were supplemented or replaced with more recently available data. When geo-referenced data were not available, we worked with experts to create GIS layers such as the leatherback sea turtle layer. Much of the new information was obtained because of its relevance to resource management actions or concerns in MBNMS. In spite of our best efforts, it is likely that some sections of this report do not contain all the most recent information available in the scientific literature.

Organization of Report

The main body of this report is divided into sections by habitat; primary habitat sections are presented first, followed by secondary habitat sections. The 11 primary habitat categories originally identified as occurring in MBNMS resulted in only 6 primary habitat sections because: nearshore habitats were excluded (not in the federal study area); shelf I and shelf II were combined due to substantial overlap in the information found for this depth range; and no information was found for hard substrate in the rise (except on seamounts).

Each habitat section begins with a **Habitat Overview** - a brief description of the focal habitat. Next, a **Search Topic Table** provides an overview of the information found during the literature review for the focal habitat. The table lists the search topics as organized in Table 1. When information was found for a search topic in the focal habitat, the page number where that information is located in the habitat summary is provided. If little or no information was found, then a brief summary is provided or related information available in other habitat sections is noted. The remainder of the section is the **Habitat Summary**, which contains a detailed description of the information found for the focal habitat organized by search topic. Search topics without substantial information (as noted in the Search Topic Table) are omitted from the habitat summary.

Species of Special Interest

Some species in MBNMS are the focus of a higher level of interest and attention from resource managers. This interest may be due to a variety of factors, including ecological role in the ecosystem, sensitivity to disturbance, low population size, or economic value. The following three categories were used to help identify species of special interest to resource management in the offshore habitats of MBNMS:

- Species landed in MBNMS[2]
- Endangered and Threatened Species
- Other At-Risk Species

[2] The listing category, "Species Landed in the MBNMS" only applies to invertebrates and fishes. Seabirds, marine mammals, and reptiles are protected from take by one or more of the following laws: the Migratory Bird Treaty Act, the Marine Mammals Protection Act, and the Endangered Species Act.

Appendix A in Starr et al. (2002a) was used to identify species landed in MBNMS. Endangered and threatened species includes species listed under the federal Endangered Species Act (ESA) and the California Endangered Species Act (CESA). Other at-risk species includes species listed as "Critically Endangered", "Endangered" or "Threatened" on the International Union for Conservation of Nature (IUCN) Red List, species listed as "Candidate Species" or "Species of Special Concern" under the ESA or CESA, and fish stocks listed as "Overfished" by the National Marine Fisheries Service (NMFS).

In addition, MBNMS staff identified species that do not appear on these lists, but have been the focus of resource management interest in the sanctuary. For example, both the state of California and the National Marine Fisheries Service recently created prohibitions on the harvest of krill in the waters off California to assure the protection of this resource for the marine mammals, seabirds, and fishes that rely on krill as a primary food source.

The species of special interest list is presented in a series of tables with each table representing a major taxonomic group: invertebrates (Table 3); fishes (Table 4); reptiles (Table 5); seabirds (Table 6) and marine mammals (Table 7). These tables show only a subset of all the species that occur in MBNMS because the tables include only species that are of special interest to resource management and occur in one, or more, offshore habitats (species only found in nearshore habitats were excluded).

Many of these species are of special interest to resource management because their abundance is reduced compared to historic levels. Population status information, including biomass levels compared to historically high levels (e.g., 50%) and recent trend in abundance (e.g., increasing, decreasing), is provided when available (Table 3-7). Listing status and population status information was updated in May of 2012. Data sources for population status information are footnoted in the tables.

Habitat distribution in the benthic, open water and submarine canyon habitats is provided for all species of special interest. Though most species are either benthic or pelagic, some species are associated with both the open water and benthic habitats. For example, some pelagic predators (e.g., California sea lions) also forage on benthic organisms and some fishes (e.g., blue rockfish) with a benthic adult phase have a pelagic juvenile phase. Species were indicated as being associated with submarine canyon habitat if they have been observed in submarine canyons or their distribution in the water column appears to be influenced by features associated with submarine canyons. For example, blue whales are commonly observed foraging on prey aggregations in canyon heads.

For invertebrates and fishes (Tables 3 and 4, respectively), habitat distribution information is provided for both juvenile and adult phases when available. We used the following references to compile habitat distribution information (e.g., substrate preferences, depth zones) for invertebrates and fishes: Miller and Lea 1972, Morris et al. 1980, Eschmeyer et al. 1983, Love 1996, Cailliet et al. 2000, Leet et al. 2001, Warner et al. 2001, Love et al. 2002, Starr et al. 2002a, Ebert 2003, Animal Diversity Web 2005, CDFG 2005, Fishbase 2005, NCCOS 2005.

For sea turtles, seabirds, and marine mammals (Tables 5-7, respectively), a species was only indicated as occurring in a benthic habitat category if it interacts with the benthos, such as foraging on benthic or benthopelagic organisms. We used the following references to compile habitat distribution information for turtles, seabirds, and mammals: Keitt et al. 2000, Folkens 2002, Roberson 2002, NCCOS 2003, Birds of North America Online 2005, CDFG 2005, NCCOS 2005.

Spatial Data Layers and Maps

Geo-referenced data layers were gathered during literature searches and expert interviews and assimilated in GIS. We focused on assimilating the most recent, complete and comprehensive data from authoritative sources and data that could provide broad overviews of the distribution of the resources in the offshore habitats of MBNMS.

A variety of data layers were compiled in this natural resources assessment including:

- Geological features such as hard substrate, seamounts and submarine canyons;
- Oceanographic features such as upwelling zones, the oxygen minimum zone, and fronts;
- Biological resources such as structure-forming species (e.g., deep-sea corals, CBCs) and species of special interest (e.g., seabirds, marine mammals, groundfish).

Some data are based on field observations (e.g., ROV surveys, trawl surveys), some are based on the outputs of models (habitat suitability for deep-sea corals, densities of cetaceans), and some are based on expert opinion informed by field observations and models (e.g., leatherback turtle, seabird, and marine mammal hotspots). A table cataloging the source, availability for web download and metadata is available in Appendix II.

In order to display the data layers in the natural resources assessment, we created a bathymetric base map including national marine sanctuary boundaries, state waters[3], well-known land points, a latitude-longitude grid, depth zones, and substrate type (Figure 1). This map served as the base map for the majority of the figures, allowing the viewer to easily compare the distribution of resources to the benthic habitat categories and to cross-reference the data illustrated in the different maps.

[3] "State waters" are defined as shoreline to 3 nautical miles offshore and includes Monterey Bay.

Shelf I (30-100 m) and Shelf II (100-200 m) – Hard Substrate

HABITAT OVERVIEW

Subtidal rocky reefs in MBNMS are most often associated with dense kelp forests visible from shore and popular among SCUBA divers. However, canopy-forming kelp species are generally found on reefs that are shallower than 30 m water depth because not enough sunlight penetrates deeper waters to support the high growth rates of large kelps (e.g., giant and bull kelps). Hard bottom habitat on the shelf (between 30 and 200 m) is rare, constituting only 1.68% of the benthic habitat in MBNMS (Figure 1). Within the federal study area, hard bottom habitats on the shelf comprise approximately 75 km^2, which is 0.68% of the study area (Table 2).

Though canopy-forming kelps are absent from hard bottom habitats deeper than 30 m, smaller forms of brown and red algae grow on hard substrate down to a depth of between 60 and 75 m depending on local environmental conditions. Rocky reefs on the shelf provide habitat for many species of invertebrates that require hard substrate for attachment (e.g., corals, sponges). The complex physical structure created by boulders, caves, pinnacles, and outcrops are a favorite habitat of many species of fish. The marcoalgae and large, erect invertebrates that grow on the surface of these rocks create biogenic structure that enhances the diversity of microhabitats and provides food, shelter and surface area for settlement and retention of other organisms. Pelagic predators, including large fishes, seabirds, and marine mammals, hunt for fish and invertebrate prey along the benthos.

Much less is known about the hard bottom communities on the shelf than is known about coastal kelp forests because most researchers using SCUBA equipment are limited to waters less than 30 m deep. Until recently, Remotely Operated Vehicles (ROVs) used to study deep-sea habitats tended to be used in waters deeper than 200 m. Thus, there has been an information gap from 30 to 200 m. This gap is slowly being filed by research using ROVs and other technologies including camera sleds and human-occupied submersibles.

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	See page 8
Feeding Ground:	Piscivores, such as adult rockfishes, salmon, lingcod and wolf-eels, prey on YOY rockfishes that school around rocky outcrops on the shelf (Cascorbi 1999a). Various seabirds, such as Commo Murre and Brandt's Cormorant, rely on juvenile rockfishes for food (Airamé et al. 2003).
Spawning Ground:	The fish and invertebrate species that are resident on the rocky shelf use this habitat for spawning. No specific information was found on species that migrate to the hard-bottom shelf habitat to spawn.

Migratory Corridor:	See "Movement and Dispersal" section below for information on species that move through the hard-bottom shelf habitat during ontogenetic shifts and seasonal migrations.
Biogenic Habitat:	See page 9
Energy Flow:	
Primary Production:	See page 11
Benthic-Pelagic Coupling:	See page 11
Key Trophic Interactions:	See page 11
Key Trophic Cascades:	No specific information was found on this topic.
Productivity Hotspots:	No specific information was found on this topic.
HABITAT STRUCTURE	
Species Composition:	See page 12
Species Composition Shifts:	See page 17
Species Diversity and Richness:	See page 18
Biomass:	See page 19
Key Species Interactions	No specific information was found on this topic.
MOVEMENT AND DISPERSAL	See page 20
SPECIES OF SPECIAL INTEREST	See page 21

HABITAT SUMMARY

<u>HABITAT FUNCTION</u>

Functional Habitats

Nursery Habitat: Many fish and invertebrate species inhabit rocky reef on the shelf as juveniles and move to deeper reef or soft-bottom shelf and slope habitats as they mature. This pattern of movement, called ontogenetic migration, is common in rockfishes. In a review of 48 species of rockfish, Love et al. (1991) found that juveniles of 40 species recruited to water shallower than adult depth, or at least in the shallowest part of the adult range. Less is known about invertebrates. Giant octopuses find shelter in the cracks and crevices of rocky reefs on the shelf as juveniles, but adults tend to be found in deeper water (Cascorbi 1999a).

- **Rockfishes.** Shallow, high-relief rock habitat inside and adjacent to Big Creek Ecological Reserve in central California appeared to serve as a nursery habitat for young-of-the-year (YOY) rockfish (Yoklavich et al. 2002). The density of YOY rockfishes on rock outcrops between 20-90 m ranged from 27 to 857 fish/m^2 and represented 38-93% of all fishes on the outcrops (YOY rockfishes accounted for only 0.7-1.9% of the total fish at depths >100 m). A survey of recruitment habitat for YOY rockfishes in Monterey Bay identified two areas of high density in south Monterey Bay associated with low relief granite/ sedimentary rock outcrops in 80-90 m (Johnson et al. 2001). Laidig et al. (2009) found that fishes less than 20 cm accounted for over 80% of all fishes observed on low relief rocky outcrops between 65-110 m on the Davenport Shelf. The abundance of immature fishes may indicate that this area of the shelf is a nursery for younger fishes. Specifically the outer shelf may be an intermediate staging area between the shallow, nearshore YOY habitats and deeper, adult habitats.

Biogenic Habitat: Macroalgae and structure-forming invertebrates attach to hard substrates on the shelf creating biogenic habitats. Structure-forming species contribute significantly to benthic habitat structure and function by adding vertical relief, increasing the diversity of microhabitats, and increasing the surface area for settlement and retention of other organisms.

- **Deep-water Algae in Central California** (Spalding et al. 2003). Deep-water algae are a biogenic habitat on hard bottom from 30-75 m deep (Figure 7). Macroalgae can have profound effects on the local abundances of fishes by providing shelter for juveniles and adults and by providing a habitat for small invertebrate prey.
- **Structure-forming Invertebrates.** Sessile, erect megafaunal invertebrates contribute significantly to benthic habitat structure and function through large size, complex morphology or the ability to form high density aggregations (Tissot et al. 2006). These invertebrates add vertical relief, increase the diversity of microhabitats, and increase the surface area for settlement and retention of other organisms. Biogenic habitat may be especially important where the physical habitat lacks large structural relief or complexity. Managed fish species associated with structure-forming invertebrates include: lingcod, longspine and shortspine thornyhead, sablefish, spotted ratfish, and rockfishes (e.g., bocaccio, cowcod, flag, greenspotted, quillback, rosethorn, sharpchin, starry, tiger, vermillion, yelloweye, and yellowtail) (NMFS 2005, Tissot et al. 2006). Structure-forming invertebrates are susceptible to damage from physical structures dragged across the seafloor including anchor lines and fishing gear. Growth rates for many of these invertebrate species are low, extending the time to recovery if these communities are damaged.
    - **Structure-forming Invertebrates in MBNMS** (MBARI VARS database 2011). The locations where Monterey Bay Aquarium Research Institute (MBARI) scientists have observed structure-forming invertebrates associated with hard substrates are shown in Figure 8. These observations of soft corals, stony corals, black corals, hydrocorals, crinoids and sponges were made during ROV surveys in 1989-2009. Each data point represents a sighting regardless of the abundance of the organisms in the video frame. It is important to note that these organisms are likely to occur in portions of MBNMS that have not been sampled by MBARI.
    - **Deep-sea Corals Collected in Bottom Trawls in MBNMS** (Curt Whitmire, pers. comm.). The locations where deep-sea corals were collected incidentally in bottom trawl surveys by the National Marine Fisheries Service (1980-2010) are shown in Figure 9. Records represent the presence of a given taxonomic group in the area swept by trawl gear; exact location, species, and abundance information is not available. Corals from the following taxa likely were associated with hard substrate: Antipatharia (black corals), Alcyonacea (soft corals), Anthoathecata, Scleractinia (stony corals), and Gorgonacea (gorgonians). It is important to note that these trawl surveys were designed

to monitor groundfish populations (not corals) and the surveys occurred mostly over low-relief, soft bottom. Trawl gear is not designed to sample the habitats in which many coral taxa reside, particularly those habitats characterized by rocky substrate and high relief.

- **Structure-forming Invertebrates Observed in MBNMS Shelf Characterization Surveys** (IfAME and MBNMS 2011). Video transects using a remotely operated vehicle (ROV) and a towed camera sled were made to characterize the distribution of fishes, invertebrates, and seafloor habitats on the continental shelf (50-200 m) and upper slope (200-400 m) at five locations in MBNMS: Ascension and Año Nuevo Canyons; North Monterey Bay; Carmel Bay and Point Lobos; Point Sur Shelf; and La Cruz Canyon and Point Piedras Blancas. Transects covered a varied of substrate types including rock ridges, bolder, and cobble. Structure-forming species commonly observed in this study include brachiopod beds, plumose anemones (*Metridium farcimen*), sponges, basket stars, crinoids, and gorgonians. Specific locations where structure-forming invertebrates were observed along the transects are available through the Shelf Characterization and Image Display website (http://sep.csumb.edu/ifame/scid).
- **Structure-forming Invertebrates in Central California MLPA MPAs** (Starr and Yoklavich 2008). A manned submersible was used to characterize the benthic habitat and associated invertebrates in the deep portion (24-365 m) of eight of the new central California Marine Life Protection Act marine protected areas and associated reference sites. Structure-forming species associated with hard bottom (e.g., corals, sponges, crinoids, gorgonians) were observed at all sites. See Table 9 for a summary of locations where structure-forming species were part of the dominant megafaunal invertebrate assemblage.
- **Deep-sea Coral Habitat Suitability** (Guinotte and Davies 2012). The potential distribution of deep-sea corals was modeled for the U.S. West Coast Exclusive Economic Zone. Predicted habitat suitability in MBNMS is shown separately for 6 deep-sea coral taxa (Figure 10). Habitat suitability probabilities and areal extent of predicted habitat were highest in the sanctuary for Suborders Alcyoniina, Calcaxonia, Holaxonia, and Order Scleractinia. In contrast, suitability probabilities and areal extent were lower in these areas for Order Antipatharia (except at Davison Seamount) and Suborder Scleraxonia. The models used a variety of physical, chemical and environmental variables known or thought to influence the distribution of deep-sea corals. However, the model will likely overpredict the amount of suitable habitat in some areas (e.g., indicate suitable coral habitat in areas that are known soft bottom regions) because fine-scale bathymetric features (10’s of meters), substrate, and current data were not available for the entire study area.
- **Brachiopod Beds as Fish Habitat**. Dense brachiopod beds have been observed at many locations on the continental shelf in MBNMS (Starr and Yoklavich 2008 and IfAME and MBNMS 2011). Laidig and colleagues (2009) examined brachiopod beds as a benthic fish habitat by manned-submersible transects at depths between 65 and 110 m on the shelf offshore of Davenport. This biogenic habitat type had the lowest abundance and diversity of fishes, and only two species (greenspotted and greenstriped rockfishes) were commonly observed in and around brachiopods. A few other species,

such as small flatfishes and lingcod, were occasionally seen. It may be that brachiopod beds are not associated with suitable prey or perhaps the beds are an ephemeral habitat that is periodically covered by the surrounding sediment and not consistently available as shelter for fishes. In a separate study, small finfish (e.g., rockfish, combfish), were observed swimming above an extensive brachiopod bed while flatfishes were observed in the sandy patches between brachiopod beds (IfAME and MBNMS 2011).

Energy Flow

Primary Production: There are two main sources of primary production in rocky reef shelf habitat: deep-water algae attached to the substrate, which is only found in waters less than 75 m deep, and phytoplankton in the water column.

- **Deep-water Algae in Central California** (Spalding et al. 2003). Deep-water algae are a source of primary production on rocky reefs from 30-75 m deep. Surveys of deep-water algal communities between Point Pinos and Point Sur found that algae were present at fairly high densities from 30-45 m and beyond this depth range algal density declined with increasing depth (Figure 7). The maximum depth of algae occurrence was approximately 75 m at a site off of Point Sur where water clarity was the highest.
- **Iron Availability and Phytoplankton Productivity** (Hutchins et al. 1998; Firme et al. 2003). In MBNMS, waters over the shelf tend to be iron-replete and waters offshore of the shelf tend to be iron-limited. Iron-replete waters tend to have higher primary productivity than Fe-limited waters. See 'Open Water' habitat summary for additional information.

Benthic-Pelagic Coupling: The flux of material between the water column and benthos occurs through sinking of non-living organic matter and the active movement of organisms. Falling plankton, fecal pellets, animal carcasses, and drift algae may be deposited on rocky reefs and utilized by scavenging herbivores and detritivores. See Appendix III for more general information about this process.

- **Drift Algae**: Fronds shed by kelp growing on the rocky reef in waters <30 m may be transported by water currents and gravity to deeper sections of the reef. Spalding et al. (2003) observed a few pieces of drift kelp (*Pleurophycus gardneri* and *Eisenia arborea)* with an ROV from 60 to 80 m in central California, suggesting that drift from deep-water algal beds is transported down the reef. See 'Macrophyte Detritus' habitat summary for additional information.
- **Spawning of Pelagic Eggs/ Larvae**: The majority of invertebrates (e.g., sea urchins, sea stars) and fishes (e.g., rockfish, Hexagrammids) living associated with the rocky shelf have eggs and/or larvae that are pelagic. Therefore, reproduction is a major source of upward flux of organic matter to the pelagic compartment.
- **Settlement/Recruitment of Juveniles**: Some species, such as sessile invertebrates, have larval or juvenile phases that settle back onto the rocky shelf, while the juveniles of other species (e.g., rockfish) will settle into shallow nearshore habitats and then move at an older age to the rocky shelf.

Key Trophic Interactions: Many of the invertebrates living on the rocky shelf are either detritivores or planktivores. These organisms play an important role in the shelf food web by converting nutrients, phytoplankton, and sinking organic matter into reef-associated biomass.

- **Detritivores:** Large pieces of organic matter, such as macrophyte detritus and animal carcasses, that sink to the reef are consumed by scavengers such as crabs and shrimp. Smaller sinking organic particles, such as phytoplankton shells and fecal pellets, coat the surface of the reef and are consumed by deposit feeders (such as sea cucumbers).
- **Planktivores** (Cascorbi 1999a). Filter-feeders (such as encrusting sponges and tunicates) and suspension feeders (such as anemones and corals) catch and consume phytoplankton, small zooplankton, and other suspended organic matter that is carried over the reef by water currents.

HABITAT STRUCTURE

Species Composition: Hard substrates are suitable habitat for attachment of algae (down to 75 m) and a rich fauna of sessile and mobile invertebrates, including sponges, corals, brachiopods, crinoids, sea anemones, sea stars and sea urchins. Shale reefs, because of their softer composition, support a large abundance of rock-boring organisms, such as clams, and a variety of fish and invertebrates that use the bored holes for shelter.

Rockfishes are by far the most numerous group of fishes associated with hard bottom on the shelf, though many other fish species can be found living on and near hard bottom (especially in Shelf I). Vertical relief and rugosity of the hard substrate alters species composition, since species differentially associate with boulders, flat rock, and cobble. A high diversity of seabirds and marine mammals are observed in the waters over the shelf. All of the marine mammals and some of the seabirds are strong divers that may feed on benthic fishes and invertebrate prey on or just above the rocky reefs of the shelf.

- **Deep-water Algae in Central California** (Spalding et al. 2003). In a study of multiple sites between Point Pinos and Point Sur, 48 macroalgal taxa were found attached to hard substrate in depths exceeding 30 m. These taxa were distributed in three broadly overlapping zones (Figure 7):
  - An upper "*Pleurophycus* zone" of stipitate kelps and *Desmarestia* spp. with a high percent cover of corallines, low cover of uncalcified red algae, and rare green algae;
  - A middle "*Maripelta* zone" with common uncalcified red algae and infrequent corallines and green algae;
  - A zone of infrequent patches of nongeniculate coralline algae.

  NOTE: Many of the species identified in this study also occur in the hard-bottom nearshore (<30 m) habitat.
- **Epifaunal Invertebrates in Northern Monterey Bay** (CSLC & MBNMS 2005). Epifaunal macro-invertebrates were surveyed on hard-bottom habitats of the shelf in northern Monterey Bay. The species assemblage was characterized as follows:
  - Inner shelf (30-150 m): cup corals (e.g., *Paracyathus*, *Balanophyllia*), encrusting sponges, tunicates, gorgonians, anemones (*Metridium* and *Urticina*), and brittlestars;
  - Outer shelf (150-300 m): erect sponges, anemones (e.g., *Stomphia*, *Amphianthus*, *Metridium*), decapods, brittlestars, and sea stars;

- Many echinoderm genera (e.g., *Florometra*, *Gorgonocephalus*, *Strongylocentrotus*) were distributed over a broad depth range (100-500 m or more);
- High relief (>1 m) rocky habitat: suspension feeding cnidarians (e.g., *Lophelia,* cup corals, anemones, zoanthids), erect sponges, crinoids (e.g., *Florometra*), basket stars (e.g., *Gorgonocephalus*), and bryozoans;
- Low relief rocky habitat: species that can survive episodic sediment burial, and high loads of suspended particles in the water column. Species include anemones (e.g., *Metridium*), cup corals, and brittlestars.

- **Megafaunal Invertebrates in the MBNMS** (Graiff 2008). The abundance and distribution of megafaunal invertebrates on the continental shelf and upper slope was surveyed at three sites in the MBNMS using a manned submersible. See Table 8 for the relative abundance of megafaunal invertebrates at Portuguese Ledge (71-252 m), Point Sur (72-126 m), and Big Creek (19-249 m**)**.
- **Megafaunal Invertebrates and Fishes in central California MLPA MPAs** (Starr and Yoklavich 2008). A manned submersible was used to characterize the benthic habitat and associated megafaunal invertebrate and fish assemblages in the deep portion (24-365 m) of eight of the new central California Marine Life Protection Act marine protected areas and associated reference sites. See Table 9 for a summary of the dominant megafaunal invertebrates and the relative abundance of common groups of demersal fishes at each site.
- **Megafaunal Invertebrates** (Cascorbi 1999a, Airamé et al. 2003). Rocky reefs beyond 30 m support a rich turf of encrusting animals including: sponges (e.g., orange puffball sponge *Tethya aurantia*, cobalt sponge *Acanthancora cyanocrypt*a), anemones (e.g., strawberry anemone *Corynactis californica*, *Metridium* spp., rose anemones *Urticina lofotensis*, swimming anemone *Stomphia didemon*), cup corals (e.g., orange cup coral *Balanophyllia elegans*), hydrocorals (e.g., California hydrocoral *Stylaster californicus*), sea fans (e.g., red gorgonian *Lophogorgia chilensis*), and tube worms (e.g., feather duster worm *Eudistylia polymorpha*). Mobile invertebrates include sea cucumbers (e.g., *Parastichopus* spp.), shrimp and prawns (e.g., spot prawn *Pandalus platyceros*), and octopus. On shale reefs, rock-boring clams and date mussels bore into the reef and create holes that are inhabited by small invertebrates such as polychaete worms, snails, sea stars, small octopuses, porcelain crabs (*Petrolisthes* spp.), peanut worms, nestling clams, baby hermit crabs and gumboot chitons (*Cryptochiton stelleri*).
- **Fish at Davenport Shelf** (Laidig et al. 2009). Two species, pygmy rockfish and blackeye goby, accounted for 41% of all fishes identified between 65-110 m on the shelf offshore of Davenport. The fish assemblages were identified based on bottom habitat. Two general assemblages were observed over boulder habitat: one in which pygmy rockfish dominated (19–22% contribution), and the other without pygmy rockfish. Rosy, yellowtail, and starry rockfishes, other *Sebastomus* spp., and blackeye gobies were consistent members of both types of assemblage on boulder habitat. Other species observed in boulder habitat include boccacio, canary, greenstriped, greenspotted, squarespot, and vermilion rockfishes, kelp greenling, pink surfperch, Northern ronquil, lingcod, sculpins, and flatfishes.
- **Fishes at Point Lobos** (Anderson and Yoklavich 2007). Demersal fishes and benthic habitats were surveyed from a manned submersible in southern Monterey Bay near Point

Lobos (60-260 m). Three habitat types (hard, soft, mixed) were classified from acoustic maps. Habitat type was a strong predictor of fish assemblage composition:

- **Hard** (high relief outcrops, 60−100 m): fish assemblage characterized by schools of small-bodied rockfish species (e.g., squarespot, pygmy, and young-of-the-year), a suite of large-bodied rockfishes (e.g., bocaccio, yellowtail, flag, rosy, and *Sebastomus* spp.), and a few non-rockfish species (e.g., blackeyed goby and lingcod).
- **Mixed** (low relief outcrops, 90−150 m): fish assemblage characterized by schools of small-bodied rockfish species, halfbanded rockfish, two large-bodied rockfishes (greenspotted and greenstriped), and a variety of non-rockfish species (e.g., sanddabs, pink seaperch, combfishes, Pacific argentine, and lingcod). This habitat type had the highest species diversity, which resulted from a combination of species unique to the mixed stratum and species characteristic of both the hard and soft strata.

- **Fishes In and Around Big Creek Marine Ecological Reserve** (Yoklavich et al. 2002). At least 36 of the 82 species of fishes identified in and around Big Creek Ecological Reserve were rockfishes; 95% of all fishes surveyed at water depths of 35-100 m were rockfishes, and 64% of fishes at depths 100-250 m were rockfishes. Four distinct fish assemblages were identified between 20-250 m and two of these were associated with hard bottom:
  - Boulders and biogenic habitats (e.g., algae) on rock in shallow water (<100 m): blue, copper, gopher, halfbanded, olive, rosy and vermilion rockfishes, painted greenling, blackeye goby, sharpnose seaperch, and señorita;
  - Bedrock with uneven surface in deep water (100-250 m): bank, darkblotched, greenspotted, pygmy, rosethorn, squarespot, and yelloweye rockfish.
- **Fishes at Point Pinos and Point Sur** (Starr et al. 2006). The relative abundance of fishes was determined for shallow water (70-90 m) high-relief habitats and deep water (90-130 m) high-relief and low-relief habitats at Point Pinos and Point Sur in central California (Figure 11). Rockfishes (*Sebastes* spp.) were the most common fish observed at all sites.
  - **Shallow, high relief habitats**: Approximately 50% of the fish identified at both sites were pygmy and squarespot rockfish. Also observed in decreasing order of abundance were blackeye goby, rosy rockfish, species of the *Sebastomus* group, and yellowtail rockfish;
  - **Deep high-relief habitats**: Between 40-50% of the fishes identified at both sites were pygmy rockfish. Other species observed commonly at both sites were unidentified *Sebastes* spp. (small fish, usually young-of-the-year), members of the *Sebastomus* species complex, squarespot rockfish, and yellowtail rockfish. Point Pinos had higher abundance of lingcod and blackeyed gobies while Point Sur had high abundance of bocaccio and halfbanded rockfish;
  - **Deep low-relief habitats**: the species composition was quite different for this habitat at the two sites. At Point Pinos, halfbanded and pygmy rockfishes were observed most frequently. Also observed in decreasing order of abundance were: *Sebastomus* species complex, squarespot rockfish, blackeye goby, unidentified *Sebastes* spp., and greenstriped rockfish. At Point Sur, approximately 50% of the fish observed were pygmy rockfish. Also observed in decreasing order of abundance were: *Sebastomus*

species complex, unidentified *Sebastes* spp., squarespot rockfish, greenstriped rockfish, greenspotted rockfish and bank rockfish.

- **Fish at Cordell Bank** (Pirtle 2005). Cordell Bank has a diversity of habitats that includes high-relief rock pinnacles, flat rock, boulders, cobble, sand, and mud. Rockfishes were the most abundant fishes observed on Cordell Bank, accounting for over 90 percent of the recorded fish. Young-of-year rockfishes were the most numerous and most frequently occurring group of fishes observed on rocky regions of the bank. Pygmy rockfish, the numerically dominant adult fish, were most abundant in low relief rock and boulder habitats. Species common in shallow (40-80 m) high-relief rock habitats were rockfishes of the *Sebastomus* group, with rosy rockfish in close proximity to the substrate and yellowtail rockfish and widow rockfish primarily occupying the water column. Greenspotted rockfish, yellowtail rockfish, rosy rockfish, lingcod, painted greenling, and blackeye goby were often associated with flat rock and boulder habitats.
- **Fish-Habitat Associations at Cordell Bank** (Anderson et al. 2009). Habitat type and the associated fish fauna were surveyed between 52-365 m depth using a manned submersible. An abundant and diverse fish fauna (87,078 individuals from 70 species/ taxa in 21 families) was recorded on and around Cordell Bank and was dominated by the genus *Sebastes* (27 species, 95% of individuals). Five broad-scale habitat zones (three of which contain hard bottom shelf habitat) were characterized by distinct fish faunas, with depth and habitat composition strong predictors of fish assemblages:
    - **Slope-bank transition zone** (interwoven mud and patchy reef, 120-130 m): characterized by an array of species found in both mud (e.g., flatfishes and poachers) and patchy mud-reef habitats (e.g., shortspined combfish, sculpins, and sharpchin greenspotted, and greenstriped rockfishes);
    - **Bank** (rock–boulder–sand; 52–110 m): characterized by a diverse and abundant array of fish species that varied over its depth range:
        - **Upper bank:** characterized by schooling species (e.g., pygmy and yellowtail rockfishes) and more solitary species (e.g., rosy rockfish and lingcod);
        - **Middle bank**: characterized by a variety of schooling species (e.g., squarespot, widow, and speckled rockfishes) and solitary species (e.g., painted greenling and blackeyed goby);
        - **Deep bank:** characterized by the presence (in low numbers) of large-bodied commercial species such as bocaccio, yelloweye, canary, and vermilion rockfishes, along with small-bodied rockfishes such as swordspine rockfish.
    - **Shelf–bank transition zone** (reef–sand, 80–110 m): similar fish assemblage to that of the slope–bank transition (except in lower densities), with the addition of sanddabs and pricklebacks.
- **Fish over Hard Substrate** (Love and Yoklavich 2006). In central and northern California the following species make up the typical adult fish assemblage over rocky substrate on the shelf:
    - **Mid-Shelf** (30-100 m): Rockfishes (black, blue, bocaccio, canary, chilipepper, china, copper, cowcod, flag, halfbanded, olive, pygmy, quillback, squarespot, starry,

vermilion, widow, yelloweye, yellowtail), lingcod, kelp and painted greenling, cabezon, blackeye goby, pile perch, sharpnose seaperch, white seaperch, and wolf eel;

  - **Deep Shelf** (100-200 m): Lingcod and rockfishes (bank, bocaccio, canary, chilipepper, cowcod, darkblotched, halfbanded, greenblotched, greenspotted, pygmy, redbanded, rosethorn, sharpchin, swordspine, splitnose, vermilion, widow, yelloweye, yellowtail).

- **Rockfishes** (Love et al. 2002). The typical rockfish assemblages along the coast of central and northern California were identified for five depth categories (Table 10). The species included in the table occur over hard and soft-bottom, but the majority of the species are primarily found over hard bottom. Shelf I and II were the depth categories with the highest species richness - 23 and 22 species, respectively.

- **Groundfish Assemblages in Central and Northern California**. Using CDFG recreational hook-and-line catch data, NCCOS (2003) identified 5 depth-stratified species assemblages between 13 and 157 m (Table 11). Because rockfishes were the target of the hook-and-line recreational fishery, hard-bottom shelf was the habitat most likely sampled in this data set.

- **CPFV fishing locations based on similarities in species composition** (Sullivan 1995). Purpose of this study was to evaluate cluster analysis as a method of grouping northern and central California Commercial Passenger Fishing Vessel (CPFV) fishing locations based on similarities in species composition. Most of the fishes included in analyses were rockfishes (RF); other species included lingcod, Pacific hake, sablefish, Pacific sanddab, and petrale sole. Fishing locations ranged from Pescadero Point to Point Sur. Data set was separated into two species groups: midwater schooling species, and benthic species. For the benthic species, four location groups were geographically and bathymetrically distinct:

  - **South Shallow**: rosy and starry RF, and lingcod
  - **North Shallow**: lingcod and gopher RF
  - **Canyon Ledge**: greenstriped and greenspotted RF, sablefish, and lingcod
  - **Shelf Flats**: greenspotted, rosy, greenstriped, and starry RF, and lingcod

- **Seabirds and Marine Mammals** (Research Planning Inc. 2006). Table 12 provides a list of the seabird and marine mammals species typically observed along the central California coast and their relative abundance and seasonality in eight pelagic zones off of central California (Figure 12):

  - **Seabirds**: Of the seabird species found over the shelf, only the deepest diving seabirds, such as shearwaters and auks (e.g., murres, auklets), are capable of feeding at or near the bottom in shelf habitats;

  - **Marine Mammals**: The species most commonly observed in waters over the shelf that may feed at or near the bottom in MBNMS are northern elephant seals, harbor seals, California sea lion, Dall’s porpoise, harbor porpoise, Risso’s dolphin, and bottlenose dolphin. Sea otters tend to be found in waters less than 30 meters deep, but they are occasionally found out to a depth of 100 m.

Species Composition Shifts:

- **Natural Changes:** Significant natural changes in water temperature and current patterns, such as El Niño/La Niña events and the Pacific Decadal Oscillation, can cause shifts in species composition of the rocky shelf.
    - **Pacific Decadal Oscillation**: Beginning in mid-1970s, >20 years of a warm and plankton-depleted oceanographic regime was at least partially responsible for poor reproductive success of many fish species and may have contributed to fisheries depletion of some large rockfish species (Love and Yoklavich 2006).
    - **Fish Species Composition Shifts in Central and Southern California** (Love and Yoklavich 2006). Fish assemblages on deep (30-200 m) rock habitats off central and southern California substantially changed over the last century. Fish assemblages are now dominated by small rockfish species (e.g., halfbanded, pygmy, squarespot, swordspine) that perhaps are more productive and able to avoid capture. Many of the previously dominant, larger-sized species (e.g., canary, darkblotched, widow, bocaccio, cowcod, lingcod) are virtually absent from many areas. The authors attribute this pattern to the combination of intense recreational and commercial fishing beginning in the 1940s in combination with more than two decades (beginning in mid-1970s) of poor reproductive success of many targeted species. The low reproductive output was caused at least in part by an oceanographic regime of warm and plankton-depleted waters (i.e., the warm phase of the Pacific Decadal Oscillation or PDO)
- **Human-Induced Changes:** Humans can alter species composition on the shelf through various activities. Studies have examined the potential impacts of fishing, (including the use of bottom-tending fishing gear), laying cables, and deposition of marine debris.
    - **Fishing Effects on Megafaunal Invertebrates** (Graiff 2008). Underwater video surveys at three sites in central California were used to assess the effects of fishing on the abundance of megafaunal invertebrates categorized as slow-growing, sessile species (e.g., sponges, gorgonians) and fast-growing, mobile species (e.g., crinoids). The three sites (Portuguese Ledge, Point Sur, and Big Creek) have been subjected to varying levels of fishing intensity and gear use. Fishing intensities were calculated for recreational hook and line and five bottom-contact commercial gear types: bottom trawl, traps, bottom-set gillnet, bottom-set longline, and hook and line. Overall, there were little to no detected effects on invertebrates due to fishing. Environmental variables were most likely influencing invertebrate abundance and distribution patterns. One of the most challenging aspects of determining the impacts of fishing intensity on megafaunal invertebrates was the lack of high-resolution data on the distribution of fishing effort.
    - **Structure-forming Invertebrates**: Structure-forming invertebrates are very susceptible to damage from gear contacting the seafloor including anchors, chains, nets, pots/traps, bottom trawls and other types of fishing gear (NRC 2002, Chuenpagdee et al. 2003). Morgan et al. (2005) compared the distribution of deep-sea coral records along the west coast of North America and the distribution of groundfish landings in 2000 to determine areas of potential conflict. Groundfish landings in 2000 were confined mostly to the shelf, while deep-sea coral occurrences were greatest along the shelf break and in Monterey Canyon. This pattern suggests that either there is limited

overlap between fishery operations and deep-sea corals, or that fishing has already had substantial negative impact on coral occurrences.

- **Relative Impacts of Recreational and Commercial Fishing on Size Structure and Species Composition of Rockfishes** (Southern California Bight; Schroeder and Love 2002). In southern California, the area open to all fishing had the highest density of rockfishes (7,212 fish/ha), but the size structure and species composition were dominated by small fishes. The area open only to recreational fishing had the lowest rockfish density (423 fish/ha) and a size structure also dominated by small fishes. In contrast, the *de facto* protected area possessed high fish density (5,635 fish/ha) and the size structure and species composition shifted toward larger fishes. Cowcod and bocaccio had 32-fold and 408-fold higher densities in the *de facto* reserve than inside the recreational fishing area, and 9-fold and 18-fold higher densities than in the area open to all fishing. Recreational fishing was found to have a strong impact on species composition, size structure, and density.
- **Effects of Demersal Marine Debris** (Watters et al. 2010). Video surveys in central California of the seafloor at depths of 20-365 m observed various type of debris including monofilament line, longlines, nets, traps, beverage cans, bottles, anchors, cables, household items, and construction items. By providing artificial habitat to demersal organisms, debris can alter seafloor habitat and species assemblages. The majority of debris (e.g., 99% of 815 items surveyed in 2007) was colonized moderately to heavily by encrusting invertebrates. In surveys during the 1990s, 13% of debris items had fishes associated with them, and 38% were associated with large, structure-forming invertebrates. In 2007, less than 10% of debris items had fishes associated with them, and 30% were associated with large, structure-forming invertebrates. Fishes only associated with types of debris that could provide structure and cover; they did not associate with monofilament line. Debris occurred disproportionately in rock compared to soft sediment habitats likely due to concentrated recreational fishing effort for rockfishes (*Sebastes* spp.), which occur in complex rock habitat where monofilament line can be snagged.

Species Diversity and Species Richness: Species diversity and species richness of deep-water algae declines with increasing depth and decreasing light levels. The diversity and richness of the fish assemblage on the rocky shelf appears to increase with depth.

- **Deep-water Algae in Central California** (Spalding et al. 2003). Forty-seven species of algae occur on rocky habitats between 30 and 75 m depth. Species diversity declined with increasing water depth. Taxonomic diversity was highest for the non-coralline red algae (28 species) and brown algae (11 species) and lowest for the green algae (4 species) and coralline red algae (4 species).
- **Fishes of California** (Allen and Pondella 2006). The authors provided H' (diversity) and S (species richness) for 36 marine habitat types and for 14 major marine habitats in California. The mid-depth reef (Shelf I & II) in the central region had 7th highest species diversity recorded in the comparison (H` = ~2.8) and was the highest diversity habitat type in the central and northern regions. Species richness was not determined for mid-depth reef in the central region, but as a major habitat type (across all regions), mid-depth reef, with

~64 species, fell into the middle of the distribution of values for all major habitats examined.

- **Demersal Fishes at Point Lobos** (Anderson and Yoklavich 2007). Sixty-two species of demersal fishes (from 21 families) totaling 21,184 fishes were recorded during surveys from a manned submersible in southern Monterey Bay near Point Lobos (60-260 m). Species richness was determined for three habitat strata: 41 species in the hard stratum, 44 species in the mixed stratum, and 19 species in the soft mud stratum. The high diversity in the mixed stratum resulted from a combination of species unique to the mixed stratum and species characteristic of both hard and soft strata.
- **Demersal Fishes at Big Creek Ecological Reserve** (Yoklavich et al. 2002). In general, shallow-water (<100 m) fish assemblages were found to be more diverse over rock outcrops than over sand. In addition, the deeper reef (100-250 m) fish assemblage was more diverse than the shallow water assemblage.
- **Demersal Fishes at Davenport Shelf** (Laidig et al. 2009). During submersible surveys of 112 transects covering 32 km of habitat (including bolder, cobble, mud, and brachiopod beds), fishes were identified to 62 taxa, including 49 species, 7 genera and subgenera, and 6 families. Thirty-four of these taxa comprised at least 5% of the total number of fishes observed on a given transect.
- **Demersal Fishes at Cordell Bank** (Anderson et al. 2009). An abundant and diverse fish fauna (87,078 individuals from 70 species/ taxa in 21 families) was recorded on and around Cordell Bank and was dominated by the genus *Sebastes* (27 species, 95% of individuals). Mean and total species richness was determined for the five major habitat types:
  - **Mean species richness:** slope-bank transition (16 spp.) ≈ shelf-bank transition (16 spp.) ≈ bank (15 spp.) ≈ slope (14 spp.) > shelf (6 spp.)
  - **Total species richness**: slope (~55 spp.) > bank (~38 spp.) ≈ slope-bank transition (~35 spp.) > shelf-bank transition (~30 spp.) > shelf (~12 spp.)

Biomass:

- **Deep-water Algae in Central California** (Spalding et al. 2003). Biomass was highest from 30-40 m and decreased with increasing water depth to 75 m.
- **Demersal Fishes at Point Lobos** (Anderson and Yoklavich 2007). Biomass was not calculated for this study, but density of demersal fishes was provided for three different benthic habitat strata. The hard stratum appears to have the highest demersal fish biomass based on density estimates for both all demersal fishes (1,357 fishes/1000 m^2) and large-bodied (>20 cm) fishes (27 fishes/1000 m^2). The mixed stratum (862 fishes/1000 m^2) had substantially higher density of all demersal fish compared to the soft stratum (130 fishes/1000 m^2), although the density of large-bodied fish was higher in the soft stratum (21 fishes/1000 m^2) compared to mixed (4 fishes/1000 m^2).
- **Harvested Species:** Recreational and commercial harvest removes biomass of targeted fish and invertebrate populations. For some targeted species, biomass is substantially reduced compared to unfished biomass levels (Tables 3 and 4). Though extraction is the primary reason for a reduction in biomass for many species, changing oceanographic and ecological conditions are an important contributing factor for some harvested species. For the majority

of the 10 invertebrate and 156 fish stocks commonly landed in MBNMS, the status of the stock has not been assessed (Tables 3 and 4).

MOVEMENT AND DISPERSAL

Lowe and Bray (2006) reviewed the general movement patterns for reef-associated fish. Many small, benthic, reef-associated fishes (e.g., gobies) tend to exhibit small home ranges due to the availability of high-quality habitat and resources. For territorial species, home range size may be large for juveniles that are too small to effectively defend a territory and get repeatedly displaced by other territorial individuals. The home range may decrease when an individual becomes large enough to hold a small territory, and then the territory may expand as the fish gets larger. In non-territorial species, home range size often increases with body size as energetic requirements increase and risk of predation decreases. Also species with stronger associations with benthic habitat tend to have smaller home ranges than species that are weakly associated with the bottom (mid-water species may have territories that are more 3-dimensional as well). Individuals living in high-quality habitat often have smaller territories than those living in lower quality habitat - thus fish density is higher in the high-quality habitat.

Some species of fish that are found on the hard-bottom shelf during one or more life stages move to adjacent habitats such as the kelp forest or deep reef on the slope. These movements may be ontogenetic (age-related), or they may be seasonal (e.g., spawning migrations). Ontogenetic movement from shallow reef to deep reef is common in rockfishes (Table 10; Love et al. 2002). For example canary rockfish and cowcod juveniles recruit to hard and soft-bottom on the inner shelf and then over time move to deeper hard-bottom habitats on the outer shelf and upper slope.

Other examples of species-specific movement patterns include:

- **Juvenile Rockfishes**: Of the 48 species of rockfish for which data were available, juveniles of 40 of these species recruit to water shallower than adult depth, or at least in the shallowest part of the adult range; individuals then move at an older stage to the depth range inhabited by adults (Love et al. 1991). Laidig et al. (2009) found that fishes less than 20 cm accounted for over 80% of all fish observed on low relief rocky outcrops between 65-110 m on the Davenport Shelf. The abundance of immature fishes may indicate that the outer shelf is an intermediate staging area between the shallow, nearshore juvenile habitats and deeper, adult habitats.
- **Rockfishes in Central California** (Lea et al. 1999). Twenty-one species of rockfish (RF) and 8 additional species of fish, including cabezon, kelp greenling, and lingcod, were tagged and released to study patterns of movement at various dive and fishing sites along in central California. Of 7332 tagged fish, 197 (3%) representing 15 species, were recaptured. Most nearshore and shelf rockfishes appear to be highly residential, though a few exhibited substantial movement. The following general movement patterns were observed for each species (number of observations included in parentheses when available):
    - **No movement** (recaptured at the same general locality as release): black RF (4), black-and-yellow RF (10), blue RF (18), bocaccio (3), brown RF (1), China RF (1), copper RF, gopher RF, kelp RF (11), olive RF, vermillion RF (4), yellowtail RF (4), cabezon (3), lingcod (31);

    - **Limited movement** (up to 1.5 nm over same reef system as release): copper RF, gopher RF, olive RF, lingcod (1);
    - **Substantial movement** (more than 1.5 nm): canary RF (3), yellowtail RF (5), lingcod (7).
- **Rockfishes on Cordell Bank** (Anderson et al. 2009). High densities of young-of-the year (YOY) rockfishes were observed on the upper reaches of Cordell Bank (2,081 YOYs/1000 m^2) and moderate densities of juvenile and adult rockfishes were observed on the lower bank and transition zones. While many commercial fish species were recorded, only 7% of the fish assemblage was of harvestable size. These large adult rockfishes occurred mainly around boulders and overhangs in deep sections and transition zones, whereas YOY rockfishes occurred in highest densities in the shallowest regions of the bank, indicating that for some species ontogenetic shifts may be important.
- **Blue Rockfish** (Miller and Geibel 1973). Of the tagged blue rockfish that were recaptured inside kelp beds in Monterey Bay over a 3-year period, 95% were recaptured at the release site. Of the recaptured adult blue rockfish from tagging outside kelp beds, 85% moved <1.6 km.

SPECIES OF SPECIAL INTEREST

Many species of special resource management interest are found in the hard-bottom shelf habitat of MBNMS (Tables 3-7).

- ***Species Landed in MBNMS***: Of the 10 invertebrate and 156 fish taxa that are commonly caught and sold in the commercial and/or recreational fisheries of MBNMS (Starr et al. 2002a), 7 invertebrates and 82 fishes taxa occur in hard-bottom, shelf habitats. More landed fish and invertebrates occur in the shallower habitats of Shelf I than Shelf II.
- ***Endangered and Threatened Species****:* There are no known endangered or threatened invertebrate or fish species associated with hard-bottom, shelf habitat. Of the 3 listed seabirds and 10 listed marine mammals, only Steller sea lions and sea otters are likely to interact strongly with benthic resources on the shelf.
- ***Other At-Risk Species****:* None of the invertebrate taxa in the federal waters of MBNMS are listed as "At-Risk". Five at-risk fishes occur in hard-bottom, shelf habitats. Of the 11 at-risk seabirds and 9 at-risk marine mammals, only the deepest diving seabird (Pink-footed Shearwater) and marine mammals (sea otters and Steller sea lion) are likely to interact strongly with benthic resources on the shelf.

Additional species of special resource management interest in the hard-bottom shelf habitat include:

- Structure-forming invertebrates, such as corals and sponges, due to their important ecological role in creating habitat structure and their vulnerability to disturbance from human activities;
- Sooty Shearwaters which reach extremely high densities during the summer, when hundreds of thousands of adults forage for fishes and squid in sanctuary waters after migrating from the southern hemisphere;

- Seabirds (e.g., Common Murres, Rhinoceros Auklets, Brandt's Cormorants) and marine mammals (e.g., harbor seals, harbor porpoise, elephant seals, sea otters) vulnerable to disturbance, injury or death from human activities in the sanctuary such as oil spills and entanglement in fishing gear.

Shelf I (30-100 m) and Shelf II (100-200 m) – Soft Substrate

HABITAT OVERVIEW

The continental shelf is the gradually sloping submerged margin of a continent that extends from shore to the shelf break. Beyond the shelf break the continental slope descends more steeply to the ocean floor. In the sanctuary, the continental shelf is relatively broad from the northern boundary to southern Monterey Bay. The shelf narrows considerably south of Monterey Bay and remains narrow throughout most of the southern portion of the sanctuary, except around Point Sur and near the southern boundary in Cambria. The shelf edge is marked by the abrupt break in slope that occurs at a depth of 100-140 m (Greene et al. 2002). The vast majority (~ 93%) of the shelf in Monterey Bay National Marine Sanctuary is composed of soft bottom habitats (Figure 1). Within the federal study area, soft bottom habitats on the shelf comprise approximately 957 km^2, which is 8.7% of the study area (Table 2).

Water motion, such as waves, surge and currents, organize soft sediment particles into different group sizes. Sandy bottom is generally found in shallow waters of the shelf (<40 m depth). The shelf is a prominent feature of the northern part of the sanctuary. There, the sediments on the outer shelf are generally coarser than those on the upper slope and on the middle of the continental shelf (mid-shelf "mud belt"; Storlazzi and Reid 2010). This is likely due to large internal waves breaking at the shelf break winnowing out the finer-grained material that dominates the middle of the shelf and the continental slope (Curt Storlazzi, pers. comm.).

The lack of hard substrate for attachment prevents algae and some invertebrates from colonizing soft bottom habitats. Soft-bottom associated species live either on the surface or buried in the sediments. Some of these animals, such as the burrowing tube anemone, build somewhat permanent tubes and burrows. The burrowing activities of fishes and invertebrates mix the surface sediments and also add some structural relief to a relatively flat habitat. Large sessile and sedentary invertebrates, such as sea pens, create structural relief also.

SEARCH TOPIC TABLE

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Feeding Ground:	See page 25
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Migratory Corridor:	See “Movement and Dispersal” section below for information on species that move through the soft-bottom shelf habitat during ontogenetic and seasonal migrations.
Biogenic Habitat:	See page 26
Energy Flow:	

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HABITAT STRUCTURE	
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HABITAT SUMMARY

HABITAT FUNCTION

Functional Habitats

Nursery Habitat: The soft-sediments of the continental shelf are used as a nursery habitat by a number of fish and mobile invertebrates species. All of these species show a similar life history pattern; after a pelagic larval phase, the juvenile phase recruits to the relatively shallow and warmer waters of the continental shelf. Then, as they grow and mature, individuals gradually migrate to the colder, darker, and deeper waters of the outer shelf, slope, and submarine canyons.

- **Spot Prawn.** Based on a shallow water trap survey for juvenile spot prawn in Howe Sound (British Columbia), catch of juveniles was highest at depths of 46-60 m (Sloan 1987). Although juvenile size did not vary in a depth-related pattern, mean size of mature males increased with depth. A similar trend of male size increasing with depth was found in a study of spot prawn catches in and around the Carmel Bay Ecological Reserve in central California (Schlining and Spratt 2000). The authors of this study suspected that juvenile prawns were using shallow waters as a nursery ground.
- **Stripetail Rockfish** (Yoklavich et al. 2002). Based on ROV surveys in and around Big Creek Ecological Reserve, low relief fields of coarse sand and sea pens in about 70 m of water appeared to be a nursery ground for stripetail rockfish.
- **Rockfishes** (Johnson et al. 2001). The soft-bottom shelf in the Monterey Bay was recruitment habitat for 15 species of rockfish in 1995 and 1996. Greenstriped, stripetail, and cowcod were most abundant, followed by chilipepper, halfbanded, darkblotched, and splitnose. The highest densities were collected from 60-100 m. Peaks in birth dates

corresponded to periods of increased upwelling; peaks in settlement followed upwelling. Growth rates declined during months of highest sea-surface temperature. Juveniles ontogenetically moved toward adult depths and most left the area during the onset of winter storms.

- **Sablefish and Shortspine Thornyhead** (Jacobson et al. 2001). In benthic surveys between central California and Washington at depths of 183-1280 m, the smallest sablefish were collected at 183-364 m and the smallest shortspine thornyheads at 183-547 m. Large individuals occupied the entire range of depths, but they were relatively rare in the shallowest part of the range. The shallow areas appeared to be primarily juvenile habitat for these two species.
- **Rex and Dover Sole.** Juvenile rex sole were commonly found on the outer edge of the California continental shelf at depths of 150-200 m, which may be a nursery area for this species (Leet et al. 2001). Repeated surveys of the shelf and upper slope off Oregon, indicated that the nursery area for age-2 to -5 juvenile Dover sole was found at 80-119 m (Toole et al. 1997). This preferred nursery habitat was found to have elevated prey biomass. Earlier beam trawl surveys in Oregon indicated that rex and Dover sole may use the outer continental shelf-upper slope region (150-260 m) as a nursery during early benthic life (Pearcy et al. 1977).

Feeding Ground: The continental shelf is a feeding ground for a number of species, particularly during the summer months, when high productivity in the waters over the continental shelf may support an increase in biomass of prey species, such small crustaceans, krill and copepods. The spawning activities of large schools of market squid draw predators and scavengers to sandy shelf habitats.

- **Squid Predators and Scavengers** (Cascorbi 1999b). During spawning season, actively spawning adults, benthic egg masses, and the sinking carcasses of dying adult squid provide large amounts of food for predators and scavengers including rockfishes, sharks, seals, sea lions, Dungeness crab, bat stars, and sea urchins.
- **Pacific Hake** (Baily et al. 1982). The most abundant age classes in the Monterey area are age 2-4 (though some age 5-9 individuals are also present). Hake show an inshore-offshore movement pattern (spring and early summer over the slope, summer to <100 m depth, and offshore again in early August). The food of juvenile hake is mainly copepods and krill. Smaller adults eat mostly krill and large adults eat mostly other fish and shrimp.
- **Juvenile Dover Sole** (Toole et al. 1997). Food for juvenile Dover sole less than 100 mm total length consists of 90% crustaceans and polychaete worms and 10% mollusks. Off Oregon, the edible biomass of this prey was greatest at 100-102 m, a depth that coincided with the highest density of age-2 to -5 juvenile Dover sole (80-119 m).
- **Herring** (Hay and McCarter 1997). Pacific herring (*Clupea pallasi*) life history is closely associated with the continental shelf (<200 m) and adjacent coastal areas. The shelf area appears to be the summer feeding habitat for Pacific herring.

Spawning Ground: The fish and invertebrate species that are residents of the soft-bottom shelf use this habitat to spawn. In addition, some species, such as flatfishes and market squid, also move to specific depth zones on the shelf to spawn.

- **Market Squid** (Forsythe et al. 2004). In 2000 and 2001, market squid spawning grounds were located on open, sandy substrate in depths of 20-60 m in southern Monterey Bay (just beyond the kelp beds). Small groups of squids (20-200 individuals) generally descended during the day and laid eggs for several hours before rejoining schools in the water column (there was no evidence of death immediately after mating).
- **English Sole** (Lassuy and Moran 1989). English sole most likely spawn over sand and sand-mud bottoms at depths of 60-110 m. Spawning is usually most intense during winter, but is known to occur in all seasons. These suggested spawning times and locations are inferred from the spatial and temporal distribution of either turgid or spent females or the egg and larval stages from studies along the west coast.

Biogenic Habitats: Structure-forming invertebrates primarily associated with soft sediments include sea pens, sea whips, and brittle stars. In general, these invertebrates provide some of the only emergent structural relief to the surface of soft-bottom habitats, especially when they aggregate in high numbers. Aggregations may provide significant structural relief for fishes in mud- and sand-dominated habitats (Tissot et al. 2006). Structure-forming invertebrates are susceptible to damage from physical structures dragged across the seafloor including anchor lines and fishing gear. Growth rates for many of these invertebrate species are low, extending the time to recovery if these communities are damaged.

- **Sea Pens**. Sea pens were some of the most abundant epifaunal invertebrates observed in soft-bottom habitats of the shelf (40-140 m) in northern Monterey Bay (CSLC & MBNMS 2005). Low relief fields of coarse sand and sea pens in about 70 m of water in and adjacent to Big Creek Ecological Reserve appeared to be a nursery ground for stripetail rockfish (Yoklavich et al. 2002).
- **Sea Pen Observations in MBNMS** (MBARI VARS database 2011). The locations where Monterey Bay Aquarium Research Institute (MBARI) scientists have observed sea pens (Order Pennatulacea) are shown in Figure 13. These observations were made during ROV surveys 1989-2009. Each data point represents a sighting regardless of the abundance of the organisms in the video frame. Sea pens can be fairly abundant on the seabed, so the map generally reflects where sampling has occurred. It is important to note that sea pens are likely to occur in portions of MBNMS that have not been sampled by MBARI.
- **Structure-forming Invertebrates Observed in MBNMS Shelf Characterization Surveys** (IfAME and MBNMS 2011). Video transects using a remotely operated vehicle (ROV) and a towed camera sled were made to characterize the distribution of fishes, invertebrates, and seafloor habitats on the continental shelf (50-200 m) and upper slope (200-400 m) at five locations in MBNMS: Ascension and Año Nuevo Canyons; North Monterey Bay; Carmel Bay and Point Lobos; Point Sur Shelf; and La Cruz Canyon and Point Piedras Blancas. Transects covered a varied of substrate types including mud and sand. Structure-forming invertebrates commonly observed in soft-bottom habitat include sea pens, sea whips, and brittle starts. Specific locations where structure-forming invertebrates were observed along the transects are available through the Shelf Characterization and Image Display website (http://sep.csumb.edu/ifame/scid).
- **Deep-sea Corals Collected in Bottom Trawls in MBNMS** (Curt Whitmire, pers. comm.). The locations where deep-sea corals were collected incidentally in bottom trawl surveys by

the National Marine Fisheries Service (1980-2010) are shown in Figure 9. Records represent the presence of a given taxonomic group in the area swept by trawl gear; exact location, species, and abundance information is not available. Of the 6 coral taxa collected, sea pens (Order Pennatulacea) are the only taxa associated with soft sediments. Sea pens were the most frequently collected taxa, which is likely due to the fact that the trawl surveys were targeting groundfish in low-relief, soft bottom habitats.

- **Structure-forming Invertebrates in Central California MLPA MPAs** (Starr and Yoklavich 2008). A manned submersible was used to characterize the benthic habitat and associated invertebrates in the deep portion (24-365 m) of eight of the new central California Marine Life Protection Act marine protected areas and associated reference sites. Structure-forming species associated with soft bottom (e.g., sea pens, sea whips, brittle stars) were observed at most sites. See Table 9 for a summary of locations where structure-forming species were part of the dominant megafaunal invertebrate assemblage.

Energy Flow

Primary Production: Phytoplankton is the only source of primary production in the waters over the soft-bottom shelf. In some portions of the open ocean there is sufficient sunlight to support photosynthesis down to 200 m. However, high turbidity in coastal waters decreases the depth at which photosynthesis can occur.

The photosynthetic rate of phytoplankton is influenced by the availability of iron. In MBNMS, the primary source of iron during upwelling season consists of sediments re-suspended from the continental shelf. In areas with a wider continental shelf, such as the area between Monterey Bay and San Francisco Bay, upwelled waters interact extensively with shelf sediments and carry high amounts of iron into surface waters (Firme et al. 2003). In areas with a narrower shelf, such as the coast of Big Sur, upwelled waters have a more limited interaction with shelf sediments, and the surface waters in these areas tend to be more iron limited (Firme et al. 2003). Thus, rates of photosynthesis tend to be higher in areas with wider continental shelves. See 'Open Water' habitat summary for additional information.

Benthic-Pelagic Coupling: The flux of material between the benthos and the overlying water column occurs through the sinking of non-living organic matter and the active movement of organisms. Falling animal carcasses and drift algae may be deposited on the seafloor and utilized by scavenging herbivores and detritivores. See Appendix III for more general information about this process.

- **Drift Algae:** Drift algae settling to the seafloor is a source of organic matter for benthic organisms. Drift algae may not accumulate as readily on the soft-bottom shelf as it does in other habitats, such as submarine canyons. In central California, lower biomass of drift algae was observed at sites on the shelf and slope near Point Joe (87-357 m) as compared to shallow and deep sites in Carmel Canyon (Harrold et al. 1998). This lower biomass may have been due to lower flux and/or higher consumption by resident herbivores (e.g., urchins), which were at higher density on the shelf. Vetter and Dayton (1998) reported similar results – lower biomass of drift algae at sites on the shelf and slope than in La Jolla Canyon. See the "Macrophyte Detritus" habitat section for additional information.

- **Spawning of Pelagic Eggs/ Larvae:** The majority of infaunal and epifaunal invertebrates (e.g., tube worms, brittle stars) and demersal fishes (e.g., flatfishes) living in soft-bottom shelf habitats release eggs and/or larvae that are pelagic. Therefore, reproduction contributes significantly to the upward flux of organic matter from the seafloor to the pelagic compartment.
- **Squid Egg Beds**. The deposition of benthic eggs by pelagic organisms can be a significant downward flux of organic matter to the seafloor. Foote et al. (2006) surveyed benthic egg masses of market squid (*Doryteuthis opalescens*) on the sandy shelf of southern Monterey Bay. In a selected quadrat, the estimated density of eggs was 47,720 eggs/m^2.
- **Settlement/Recruitment of Juveniles:** Some species (e.g., sea pens) have juvenile phases that settle back into the adult habitat, while the juvenile of other species (e.g., Dungeness crabs, flatfishes) settle into shallow nearshore and estuarine habitats and then move at an older stage to the soft-bottom shelf.

Key Trophic Interactions: Many of the invertebrates living on the soft-bottom shelf are either detritivores or planktivores. These organisms play an important role in the shelf food web by converting phytoplankton, sinking organic matter and nutrients into shelf-associated biomass.

- **Planktivores** (Cascorbi 1999b). Brittle stars carpet the soft-bottom shelf in some areas. While buried beneath the surface they use their long arms to catch plankton in the water column. Sea pens, sea whips, and tube anemones are examples of suspension feeders that use either stinging cells or sticky mucous to capture phytoplankton, small zooplankton, and other suspended organic matter in the water column.
- **Detritivores** (Hyland 1991). The macroinfaunal communities of the continental shelf and slope in Santa Maria Basin were studied for 2.5 years. The majority of the species found in this study were deposit feeders and relied on ingestion and absorption of organic matter in the sediments for nourishment.

HABITAT STRUCTURE

Species Composition: The infaunal invertebrate assemblage in MBNMS has a high level of species richness and tends to be dominated by polychaete worms. Other abundant taxa include gammarid amphipods, bivalves, nemertean worms, and ostracods. Large epifaunal invertebrates, such as brittle stars, sea stars, sea pens, gastropods, anemones, and sea cucumbers are commonly observed on the soft sediments of the shelf beyond 30 m. The fish fauna is diverse, with flatfishes being among the most common group of fishes observed in this habitat. A high diversity of seabirds and marine mammals are observed in the waters over the shelf. All of the marine mammals and some of the seabirds are strong divers that may feed on benthic fishes and invertebrate prey.

- **Infauna in Northern Monterey Bay** (CSLC & MBNMS 2005). Infauna was sampled at multiple stations between 25 and 90 m on the shelf in northern Monterey Bay. Polychaete worms showed the highest abundance and species richness at most depths. Gammarid amphipods were relatively abundant at all stations. Some of the most abundant taxa by depth were:

- 25 m = polychaete worms (*Magelona hartmanae*, *M. sacculata*, and *Scoletoma luti*);
- 44-47 m = polychaete worms (*Chaetozone lunula*, *Aricidae* (*Acmira*) *catherinae*, and *Mediomastus* spp.), bivalves, nemertean worms, ostracods;
- 60 m = polychaete worms (*Sternaspis* nr. *fossor*), bivalves, brittlestars;
- 90 m = polychaete worms (*Mediomastus* spp. and *Spiophanes berkeleyorum*), bivalves, brittlestars.

- **Infauna near Davenport** (John Oliver, MLML, unpubl. data). In northern Monterey Bay and off Davenport, sediment cores along transects between 10 m and 2,000 m have shown distinct infaunal species assemblages that vary by depth. For the two species assemblages identified on the shelf, the ten most abundant species are listed in decreasing abundance below:
  - Mid/Outer Shelf Group (50-90 m): *Mediomastus* spp. (polychaete), *Nephtys cornuta* (polychaete), *Spiophanes berkeleyorum* (polychaete), *Cossura pygodactylata* (polychaete), *Gadila* spp. (toothshell), *Sternaspis fossor* (polychaete), *Pholoe glabra* (polychaete), *Allia ramosa* (polychaete), *Mediomastus californiensis* (polychaete), *Euclymeninae* spp. (polychaete);
  - Shelf Break Group (109-150 m): *Photis* spp. (amphipod), *Mediomastus* spp. (polychaete), *Spiophanes berkeleyorum* (polychaete), Cirratulidae spp. (polychaete), *Decamastus gracilis* (polychaete), *Photis californica* (amphipod), *Rutiderma lomae* (ostracod), *Pleurogonium californiense* (isopod), Nemertea (ribbon worm), *Euclymeninae* spp. (polychaete).
- **Infauna Northern Monterey Bay and Off San Francisco** (Nybakken 1996). The infaunas north of Monterey Canyon (16-60 m) and off San Francisco (40-600 m) were dominated by polychaete worms. The polychaete fauna had the highest species richness and this group comprised at least 50% of the total number of individuals at each site. Mollusks comprised 20-25% and crustaceans comprised 13-25% of individual organisms. Brittlestars were the only echinoderm with notable abundance
- **Infauna on the Shelf in California** (Nelson et al. 2008). Sediment grabs were used to sample the invertebrate assemblage on the shelf at 50 sites in California, including 14 sites in MBNMS. Sites ranged in depth from 28-138 m (46-112 m for MBNMS sites). Polychaetes, crustaceans and mollusks were the dominant taxa, both by percent abundance (59%, 17%, 12%, respectively) and percent species (44%, 25%, 17%, respectively). The 10 most abundant taxa were the polychaetes *Mediomastus* spp., *Spiophanes duplex*, *Spiophanes berkeleyorum*, *Chloeia pinnata*, *Myriochele striolata*, *Prionospio jubata*, and *Spiophanes bombyx*, the ophiuroid *Amphiodia urtica*, the decapod *Pinnixa occidentalis*, and the ostracod *Euphilomedes carcharodonta*.
- **Infaunal and Epifaunal Invertebrates off Pillar Point** (Kogan et al. 2006). The infauna and epifauna was surveyed on the shelf and slope between Pillar Point and Pioneer Seamount in northern MBNMS. The species assemblages at shelf sites (43, 67, 75, 140 m) were summarized as follows:
  - **Infauna:** Of the 24 infaunal taxonomic groups identified in this study, polychaete worms, nematodes, and amphipod crustaceans accounted for the majority of infaunal

abundance along the survey route (Figure 14). Polychaete worms were the most diverse taxonomic group with up to 33 taxa per station;

  - **Epifauna:** Brittle stars (Ophiuroidea), anemones (*Actiniaria*), sea pens (Pennatulacea), *Anthomastus ritteri* and gorgonians (*Alcyonaria*), and sponges (Porifera) were the most abundant epifaunal groups, accounting for 84.2% of total epifaunal abundance. Brittle stars were the most abundant group at two shelf sites (67, 75 m) while the sea pen (*Halipteris californica*) dominated the shelf/slope break site (140 m).

- **Infaunal and Epifaunal Invertebrates in Central California** (de Marignac et al. 2009). ROV surveys and sediment samples were used to study infauna and epifauna on the shelf between 113 and 152 m in June 2006. Both recently trawled and recovering sites were surveyed. The taxa observed in all surveys combined were:
  - **Infauna:** Thyasirid bivalve (*Axinopsida serricata*), polychaete worms (*Myriochele gracilis, Myriochele olgae, Spiophanes duplex, Spiophanes bombyx, Prionospio* spp., *Scoloplos armiger, Decamastus gracilis*, and members of families Terebellidae, Cirratulidae, and Maldanidae), and juvenile brittle stars (Ophiuroidea);
  - **Epifauna:** Brittle stars (*Ophiothrix* spp.), sea whips (*Halipteris cf.*), and fan worms (Sabellidae) were the most abundant epifaunal groups. A brachyuran crab (*Cancer* sp.) and an anomuran crab (possibly *Lopholithodes* spp.) were observed. Three distinct species of gastropod were recorded, the most common a *Conus* species. In addition, one moon snail (unknown species) and two cowries (possibly *Cypraea spadicea*) were observed.
- **Epifaunal Invertebrates in Northern Monterey Bay** (CSLC & MBNMS 2005). Epifauna were surveyed from 25-200 m in northern Monterey Bay. Sea pens, anemones, crabs and sea stars were common at most stations. The characteristic species assemblages by depth were:
  - 25-39 m = gastropods (most abundant), sea pens, and sea stars;
  - 40-59 m = cerianthaid anemones, sea stars (*Luidia foliolata*), sea pens, gastropods;
  - 60-139 m = sea stars (*Rathbunaster californicus*), sea pens (*Ptilosarcus gurneyi*, *Pennatula* spp.);
  - 90-139 m (adjacent to hard substrate) = sea urchins (*Strongylocentrotus fragilis*), sea cucumbers (*Parastichopus leukothele*), sea stars (*R. californicus*);
  - 140-200 m (dense shell hash) = dominated by the sea star (*R. californicus*).
- **Epifaunal Invertebrates in MBNMS** (Nybakken 1996, Cascorbi 1999b, Airamé et al. 2003). Common large epifaunal invertebrates found on soft sediments on the shelf (deeper than 30 m) in Monterey Bay include sea pens, notaspidean opisthobranchs, octopus (e.g., *Octopus rubescens*), squid (e.g., *Rossia*), sea stars (e.g., *Luidia*), tube worms, and amphipods. Some species are most often seen at night, such as brittle stars, polychaete worms, basket stars, sand stars, and short-spined sea stars. Dungeness crabs (*Cancer magister*) are concentrated on sandy to sandy-mud bottoms from the intertidal to approximately 100 m. Yellow rock crabs (*Cancer anthonyi*) inhabit open sand or soft-bottom habitats. Concentrations of ocean shrimp (*Pandalus jordani*) are found on green mud and mud-sand bottoms at depths of 50-400 m, whereas ridgeback prawn (*Sicyconia*

ingentis) are found on bottoms composed of sand, shell, and green mud at depths of 50-175 m.

- **Megafaunal Invertebrates in the MBNMS** (Graiff 2008). The abundance and distribution of megafaunal invertebrates on the continental shelf and upper slope was surveyed at three sites in the MBNMS using a manned submersible. See Table 8 for the relative abundance of megafaunal invertebrates at Portuguese Ledge (71-252 m), Point Sur (72-126 m), and Big Creek (19-249 m**)**.
- **Megafaunal Invertebrates and Fishes in central California MLPA MPAs** (Starr and Yoklavich 2008). A manned submersible was used to characterize the benthic habitat and associated megafaunal invertebrate and fish assemblages in the deep portion (24-365 m) of eight of the new central California Marine Life Protect Act marine protected areas and associated reference sites. See Table 9 for a summary of the dominant megafaunal invertebrates and the relative abundance of common groups of demersal fishes at each site.
- **Megafaunal Invertebrates and Fishes in the Gulf of the Farallones** (SAIC and MLML 1992). In 1991, fishes and megafaunal invertebrates were sampled at depths of 72-1800 m using bottom trawls in GFNMS. Benthic communities were distributed primarily by depth and the faunal community on the shelf was characterized as follows:
  - **Invertebrates**: Megafauna in the shelf community (~72-200 m) were sparse, but included the following species: sea stars (*Luidia foliolata*, *Astropecten verrilli*, *Hippasteria californica*, *Hippasteria spinosa*, *Rathbunaster californicus*), sea pens (*Stylatula* spp.), anemones (*Metridium* spp.), octopus (*Octopus rubescens*), brittlestars (*Asteronyx loveni*, *Ophuiura lutkeni*, *Gorgonocephalus euchnemis*), crabs (*Cancer magister*), opisthobranchs (*Pleurobranchaea californicus*, *Tritonia diomedia*), and sea cucumbers (*Parastichopus* spp.);
  - **Fishes**: The shelf community (~72-200 m) was dominated by fishes including Pacific sanddab, Dover sole, English sole, rex sole, slender sole, rockfishes (including chilipepper, shortbelly, and stripetail), pink seaperch, Pacific pompano, white croakers, plainfin midshipman, and big skate.
- **Megafaunal Invertebrates and Fishes at Cordell Bank** (Pirtle 2005). The species that were observed in different soft-bottom habitats over the depths range 55-250 m include:
  - **Muddy, Low or No Vertical Relief**: sea pens (*Ptilosarcus* sp. and suborder Subsellaflorae), snails (subclass Prosobranchia), box crabs (*Lopholithodes foraminatus*), urchins (*Strongylocentrotus fragilis*), Dover sole (*Microstomus pacificu*s), unknown flatfishes, poachers (Agonidae), combfish (*Zaniolepis* spp.), and spotted ratfish (*Hydrolagus colliei*);
  - **Deeper Mud** (160-250 m): galatheid crabs (*Munida quadrispina*), spot prawns (*Pandalus platyceros*), Pacific hagfish (*Eptatretus stoutii*), and deep-water rockfishes including splitnose, stripetail, sharpchin, and greenstriped;
  - **Sandy, Low-Relief** (less diverse): sea star (*Luidia foliolata*), sanddabs (*Citharichthys* spp.), sea pens (*Ptilosarcus* spp.), and brittle stars.
- **Fishes at Point Lobos** (Anderson and Yoklavich 2007). Demersal fishes and benthic habitats were surveyed from a manned submersible in southern Monterey Bay near Point.

Lobos (60-260 m). Three habitat types (hard, soft, mixed) were classified from acoustic maps. Habitat type was a strong predictor of fish assemblage composition:

  - **Soft** (homogeneous mud, 80−260 m): fish assemblage characterized by non-rockfishes (e.g., flatfishes and poachers); non-rockfishes dominated this assemblage (63% of observed fishes).
  - **Mixed** (low relief outcrops, 90−150 m): fish assemblage characterized by schools of small-bodied rockfishes, halfbanded rockfish, two large-bodied rockfishes (greenspotted and greenstriped), and a variety of non-rockfish species (e.g., sanddabs, pink seaperch, combfishes, Pacific argentine, and lingcod). This habitat stratum had the highest species diversity, which resulted from a combination of species unique to the mixed stratum and species characteristic of both the hard and soft strata.

- **Fishes In and Around Big Creek Marine Ecological Reserve** (Yoklavich et al. 2002). Using ROV surveys during 1997 and 1998, four distinct fish assemblages were identified between 20-250 m (two of which were associated with soft bottom)
  - Sand waves and shell hash in shallow water (<100 m): speckled and Pacific sanddabs, and sculpins.
  - Fine, smooth sediment in deep water (>100 m): Dover, rex, and slender soles, poachers, and Pacific hake.
- **Fish at Davenport Shelf** (Laidig et al. 2009). Two species, pygmy rockfish and blackeye goby, accounted for 41% of all fishes identified between 65-110 m on the shelf off Davenport. The fish assemblage was examined based on bottom habitat. Flatfishes, poachers, sanddabs, and greenstriped rockfishes characterized the species assemblages on mud-dominated habitat. Other species observed in mud-dominated habitat include rex sole, English sole, rock sole, greenspotted rockfish, lingcod, pink surfperch and blackeye goby.
- **Fish-Habitat Associations at Cordell Bank** (Anderson et al. 2009). Habitat type and the associated fish fauna were surveyed between 52-365 m depth using a manned submersible. An abundant and diverse fish fauna (87,078 individuals from 70 species/ taxa in 21 families) was recorded on and around Cordell Bank and was dominated by the genus *Sebastes* (27 species, 95% of individuals). Five broad-scale habitat zones (four of which contain soft bottom shelf habitat) were characterized by distinct fish faunas, with depth and habitat composition strong predictors of fish assemblages:
  - **Continental slope** (deep mud, 107–298 m): characterized by flatfishes, poachers, spotted ratfish, hagfishes, longspined combfish, and a few *Sebastes* species (stripetail, splitnose, and sharpchin rockfishes);
  - **Slope-bank transition zone** (interwoven mud and patchy reef, 120-130 m): characterized by an array of species found in both mud (e.g., flatfishes and poachers) and patchy mud-reef habitats (e.g., shortspined combfish, sculpins, and sharpchin greenspotted, and greenstriped rockfishes);
  - **Shelf–bank transition zone** (reef–sand, 80–110 m): similar fish assemblage to that of the slope–bank transition (except in lower densities), with the addition of sanddabs and pricklebacks.

- ○ **Continental shelf** (homogenous sand, 98–114 m): was depauperate compared to other zones and characterized only by sanddabs.

- **Rockfishes**. Williams and Ralston (2002) examined rockfish assemblages from southern Oregon to Point Conception using data from NMFS shelf and slope trawls over primarily soft bottom. Rockfish richness was highest at a depth of 200-250 m, where the shelf and slope meet. Depth and latitude were the main determinants of rockfish assemblages. There were four suggested species assemblages based on distribution, ordination, and partitioning analyses and three of these included shelf habitat:
  - Nearshore (50-150 m): copper, vermilion, brown, and halfbanded rockfishes;
  - Southern shelf (100-250 m; 34°N to the Mendocino Escarpment): bocaccio, chilipepper, cowcod, greenspotted, greenstriped, shortbelly, and stripetail rockfishes;
  - Northern shelf (150-250 m; 43°N to Monterey Canyon): canary, redstripe, rosethorn, sharpchin, widow, yelloweye, and yellowtail rockfishes.
  - Deepwater slope (200-500 m): aurora, bank, blackgill, darkblotched, Pacific Ocean perch, redbanded, shortspine, and splitnose rockfishes.

  NOTE: there was overlap in species assemblages between the Monterey Canyon and Mendocino Escarpment.

- **Benthic Fish and Invertebrate Assemblages** (Zimmerman 2006). Using the NMFS US west coast bottom trawl survey (55-500 m) data during 1995, 1998, and 2001, three biologically distinct assemblages occurred along the US west coast; shallow, middle, and deep assemblages. Within the MBNMS, the shallow (55-183 m) and deep (367-500 m) assemblages were prominent. A distinct middle assemblage was lacking; there was a mixing of shallow, deep, or uncertain assemblages occurring between 184-366 m.

- **Groundfish Assemblages in Central and Northern California**. Using NMFS groundfish shelf trawl data, NCCOS (2003) identified 10 depth-stratified species assemblages between 62 and 463 m (Table 11). Assemblages identified species that tended to be caught together and were named for the most influential species. Four of the assemblages (Pacific herring assemblage, halfbanded rockfish assemblage, Pacific sanddab assemblage and big skate assemblage) occurred primarily on the shelf, two occurred primarily on the upper slope, and four (chilipepper rockfish assemblage, rex sole assemblage and Pacific hake assemblage) occurred in both the shelf and upper slope area. Sampling targeted gently sloping soft bottom on the shelf and shelf break, but some gently sloping hard bottom was probably encountered (highly sloped rocky bottom was not sampled).

- **Fishes on the California Shelf.** Allen (2006) identified 'ecologically important' species in middle shelf (31-100 m) and outer shelf (101-200 m) habitats off north-central California (Cape Mendocino to San Simeon) (Table 13). Ecologically important species were defined as those occurring frequently within a depth zone and likely to play important ecological roles (generally with regard to feeding) in the soft-bottom community.

- **General Classification of California Marine Fishes.** Allen and Pondella (2006) used cluster analysis of species assemblages to determine which species occur together in particular habitats (by substrate type, depth, and latitude). The following species assemblages occur in soft bottom shelf habitats in central California:

  - Mid-Shelf Generalists: longspine combfish, pink seaperch, pixie poacher, calico rockfish, spotted cuskeel, curlfin turbot, English sole;
  - Mid- to Outer Shelf Generalists: plainfin midshipman, hundred-fathom codling, blackbelly eelpout, blacktip poacher, Pacific sanddab, slender sole;
  - Outer Shelf and Slope: Dover sole, California slickhead, longspine thornyhead, giant grenadier, black hagfish, California rattail.

- **Seabirds and Marine Mammals** (Research Planning Inc. 2006). Table 12 provides a list of the seabird and marine mammals species typically observed along the central California coast and their relative abundance and seasonality in eight pelagic zones off of central California (Figure 12):
  - **Seabirds**: Of the seabird species found over the shelf, only the deep diving seabirds, such as shearwaters and auks (e.g., murres, auklets), are capable of feeding at or near the bottom in shelf habitats;
  - **Marine Mammals**: The species most commonly observed in waters over the shelf that may feed at or near the bottom in MBNMS are northern elephant seals, harbor seals, California sea lion, Dall's porpoise, harbor porpoise, Risso's dolphin, and bottlenose dolphin. Sea otters tend to be found in waters less than 30 meters deep, but they are occasionally found out to a depth of 100 m.

Species Composition Shifts:

- **Natural Changes:** Significant natural changes in water temperature and current patterns, such as El Niño/La Niña events and the Pacific Decadal Oscillation, may lead to changes in the species composition on the soft-bottom shelf. However, no specific information was found on this topic in this habitat category during the literature review.
- **Human Induced Changes:** Human activities can alter species composition on the shelf. Studies in MBNMS have investigated the potential impacts of submerged cables, fishing, disposal of dredge material, and deposition of marine debris.
  - **Effects of a Submarine Cable on the Benthic Fauna in Northern MBNMS** (Kogan et al. 2006). The potential impacts of a submarine cable on the distribution and abundance of 17 megafaunal groups and 19 infaunal taxa were investigated using video observations and sediment cores. No cable-related changes in distribution or abundance were detected for most faunal groups. Three megafaunal groups exhibited cable-related changes at one or more stations. Sea anemones colonized the cable when it was exposed on the seafloor, and were therefore generally more abundant on the cable than in surrounding, sediment-dominated seafloor habitats. Some fishes, such as flatfishes, were more abundant near the cable, apparently due to the higher habitat complexity provided by the cable. Sea cucumbers, a minor element of the seafloor fauna, were less abundant near the cable than along the control transect at one (1700 m station) of the six stations inhabited by this group. These results suggest that the biological impacts of the cable were minor.

- **Effects of Submarine Cable on Seabed and Benthic Faunal Assemblages** (Kuhnz et al. 2011). A geological and biological sampling program was performed to assess the condition of the Monterey Accelerated Research System (MARS) cable and its potential effects on seabed geology and biology. The major conclusion of the study is that the MARS cable has had little detectable impact on seabed geomorphology, sediment conditions, or biological assemblages. Specific conclusions include the following:
  - Changes in mean grain size were undetectable in relation to the MARS cable.
  - The percent organic carbon content of sediments increased near the MARS cable at some locations, possibly due to natural variation or the effects of the cable or both.
  - Local variation in benthic megafaunal communities near (within 50-100 m) the MARS cable is minor or undetectable.
  - The MARS cable has little or no detectable effect on the distribution and abundance of macrofaunal and megafaunal assemblages on a regional scale (e.g. kilometers).
- **Effects of Bottom Trawling on Benthic Invertebrates in MBNMS.** Engel and Kvitek (1998) compared highly trawled (HT; trawled 4 times per year) and lightly trawled (LT; trawled once every 3 years) areas. The substrate was less heterogeneous in HT areas. In LT areas, detritus was more common on the surface of the substrate, large epifaunal invertebrates (e.g., sea pens, sea stars, sea anemones, and sea slugs) were more dense and infaunal polychaetes had higher species richness. Oligochaetes, nematodes, and ophiuroids were more dense in the HT area. These organisms were either opportunistic or not damaged/collected by the nets. There was no measurable difference in crustaceans, urochordates, sipunculids, other echinoderms, and echiurans between HT and LT areas. Overall, high-intensity trawling reduced habitat complexity and biodiversity while increasing opportunistic infauna and certain prey important in the diet of some commercial fish species.
- **Fishing Effects on Megafaunal Invertebrates** (Graiff 2008). Underwater video surveys at three sites in central California were used to assess the effects of fishing on the abundance of megafaunal invertebrates categorized as slow-growing, sessile species (e.g., sea pens) and fast-growing, mobile species. The three sites (Portuguese Ledge, Point Sur, and Big Creek) have been subjected to varying levels of fishing intensity and gear use. Fishing intensities were calculated for recreational hook and line and five bottom-contact commercial gear types: bottom trawl, traps, bottom-set gillnet, bottom-set longline, and hook and line. Overall, there were little to no detected effects on invertebrates due to fishing. Environmental variables were most likely influencing invertebrate abundance and distribution patterns. One of the most challenging aspects of determining the impacts of fishing intensity on megafaunal invertebrates was the lack of high-resolution data on the distribution of fishing effort.
- **Effects of Bottom Trawling on Benthic Invertebrates in Central California** (de Marignac et al. 2009). ROV surveys and sediment samples were used to compare infauna and epifauna at recently trawled sites and recovering sites on the shelf

between 113 and 152 m. Some minor, but distinct differences in faunal assemblages were observed:

- Infauna: There were no major differences in measures of species richness for benthic infauna, diversity (H′), or evenness (J′) between trawled vs. recovering site groups. There was a clear difference between benthic infaunal communities in the recovering vs. trawled areas due to differences in the relative abundances of component species. The two oweniid polychaetes, *Myriochele gracilis* and *M. olgae,* and the polychaete family Terebellidae all had significantly lower densities at trawled sites. The thyasirid bivalve *Axinopsida serricata* and the polychaetes *Spiophanes* spp., *Prionospio* spp., and *Scoloplos armiger* all had significantly to near-significantly higher abundances at trawled sites.
- Epifauna: Trawled transects were populated by sea whips and gastropods whereas transects within the recovering transects were dominated by patchily distributed ophiuroids (brittle stars). Macrofaunal species richness was very low for both actively trawled and recovering sites. The trawled site contained only six distinct species and the recovering site only three.

- **Effects of Exploitation on the West Coast Groundfish Assemblage** (Levin et al. 2006). Data from fishery-independent trawls on the soft bottom shelf and slope (55 to 366 m) conducted by NMFS from 1980-2001 along the U.S. west coast (WA, OR, CA combined), indicate that there have been fundamental changes in the fish assemblage. Populations of flatfishes, cartilaginous fishes, and small rockfishes have increased, while populations of large rockfishes have decreased. In 1977, rockfishes were more than 60% and flatfishes were 34% of the fish captured in the survey. In 2001, rockfishes were 17% of the fish captured in the survey and flatfishes were nearly 80%. The species that now dominate the assemblage have vastly different trophic roles and life-history strategies than the species they replaced.
- **Effects of Dredge Material Disposal** (Oliver and Slattery 1976). The effects of disposal of dredged material on the benthic invertebrate assemblage and subsequent recovery of the fauna was studied near the Monterey Canyon head at Moss Landing. Sediment cores contained 60% fewer individuals after disposal of dredge material. After 1.5 years, the number of individuals in sediment cores remained low, but the species diversity and evenness indices were higher than before disposal. Organisms adapted to unstable bottom conditions survived burial better than those adapted to more stable benthic conditions.
- **Effects of Demersal Marine Debris** (Watters et al. 2010). Video surveys in central California of the seafloor at depths of 20-365 m observed various type of debris including monofilament line, longlines, nets, traps, beverage cans, bottles, anchors, cables, household items, and construction items. By providing artificial habitat to demersal organisms, debris can alter seafloor habitat and species assemblages. In surveys during the 1990s, 13% of debris items had fishes associated with them, and 38% of items were associated with large, structure-forming invertebrates. In 2007, less than 10% of debris items had fishes associated with them, and 30% were associated with large, structure-forming invertebrates. The majority of debris (e.g., 99% of 815 items surveyed in 2007) was colonized moderately to heavily by

encrusting invertebrates. Fishes only associated with types of debris that could provide structure and cover; they did not associate with monofilament line. Though debris occurred disproportionately in rocky habitats, ~40% of debris was observed on soft sediments.

Species Diversity and Species Richness:
Species richness of the infaunal and the demersal fish assemblages on the shelf tends to increase with depth and peak near the shelf break. Species diversity of the fish assemblage associated with soft-bottom habitats appears to be lower than that found associated with hard-bottom habitats.

- **Infauna in MBNMS** (Nelson et al. 2008). Sediment grabs were used to sample the invertebrate assemblage on the shelf at 14 sites in MBNMS. Sites ranged in depth from 46 to 112 m. Species richness (mean number of taxa per grab) at these sites ranged from 52 to 119, with 6 of the sites having over 100 taxa. Mean H' diversity per grab ranged from 4.233 to 5.776.
- **Infauna Near Davenport** (John Oliver, MLML, unpubl. data). In northern Monterey Bay and off Davenport, the mean number of species in sediment cores increased along the shelf, peaking at 109 and 150 m (at the shelf break), and then declining along the slope to 700 m. The mean number of species per sample was similar from 700-2000 m. The number of species of crustaceans followed a similar pattern.
- **Infauna off Pillar Point** (Kogan et al. 2006). A total of 24 infaunal taxonomic groups were identified along a submarine cable between Pillar Point and Pioneer Seamount in the northern portion of MBNMS. Polychaetes were the most species rich group with up to 33 taxa per station. Species richness increased with depth along shelf and peaked at the shelf break (Figure 14).
- **Infauna from Northern Monterey Bay and off San Francisco** (Nybakken 1996). The total number of infaunal invertebrate species reported in a study in northern Monterey Bay (16-60 m) was 383 while in a study off San Francisco (40-600 m) a total 309 species was reported.
- **Infaunal and Epifaunal Invertebrates in Central California** (de Marignac et al. 2009). Infauna and epifauna on the shelf between 113 and 152 m were surveyed using an ROV in recently trawled and recovering sites. Macrofaunal species richness was very low for both actively trawled and recovering sites. The trawled site contained only six distinct species and the recovering site only three. Diversity of the macrofaunal assemblage was low in both actively trawled and recovering sites, with significant differences in mean diversity between the two sites. No major differences in measures of infaunal species richness, diversity (H′) or evenness (J′), were observed between trawled vs. recovering site groups. Mean number of taxa per sediment grab was 62 and 65 and mean H' diversity was 3.4 and 4.0 for recovering and trawled sites, respectively.
- **Megafaunal Invertebrates Inside and Outside Monterey Bay** (Oliver et al. 2011). Estimates of soft-bottom species density were obtained by sampling benthic megafaunal invertebrate communities in four major sampling programs along the coast of Central and Northern California. Three of these programs were focused around the Monterey Bay area. Samples from 30 to 2,000 m depths were analyzed. The Monterey Bay shelf was a

local hot spot for species density, peaking at 449 species/m^2 at the shelf break (100-150 m). This species density is just slightly less than the highest species densities measured worldwide (436 species/0.81 m^2). There were 337 species/m^2 in the mid-shelf mud zone (80 m). Species densities were lower on the slope. Species density was highest inside the bay (328-446 species/m^2) compared to outside (336-339 species/m^2) when comparing samples from the same water depths. The authors speculate that the highest species densities occur where ocean water exchanges energy with shoaling topography at the continental margin, bringing more food to the benthos.

- **Fish and Megafaunal Invertebrates in the Gulf of the Farallones** (SAIC and MLML 1992). Fish and megafaunal invertebrates were sampled using bottom trawls in the Gulf of the Farallones. The number of fish species collected by trawl was highest on the shelf and peaked at 85 m. The number of benthic megafaunal invertebrate species was lowest on the shelf and increased with depth.
- **Demersal Fishes at Point Lobos** (Anderson and Yoklavich 2007). Nineteen species of demersal fishes were recorded during surveys of soft mud habitat from a manned submersible in southern Monterey Bay near Point Lobos (60-260 m). Higher species richness of 41 and 44 species was observed in hard-bottom and mixed-substrate habitats, respectively. The high richness in the mixed habitat resulted from a combination of species unique to the mixed habitat and species characteristic of both soft and hard-bottom habitats.
- **Demersal Fish at Big Creek Ecological Reserve** (Yoklavich et al. 2002). Shallow-water (<100 m) assemblages were more diverse over rock outcrops than over sand. Species diversity was generally higher in deep-water habitats (100-250 m) than in shallow water (20-100 m).
- **Demersal Fishes at Cordell Bank** (Anderson et al. 2009). An abundant and diverse fish fauna (87,078 individuals from 70 species/ taxa in 21 families) was recorded on and around Cordell Bank and was dominated by the genus *Sebastes* (27 species, 95% of individuals). Mean and total species richness was determined for the five major habitat types:
    - **Mean species richness:** slope-bank transition (16 spp.) ≈ shelf-bank transition (16 spp.) ≈ bank (15 spp.) ≈ slope (14 spp.) > shelf (6 spp.)
    - **Total species richness**: slope (~55 spp.) > bank (~38 spp.) ≈ slope-bank transition (~35 spp.) > shelf-bank transition (~30 spp.) > shelf (~12 spp.)
- **Demersal Fishes in Central California** (NCCOS 2003). Rockfish species richness tended to be highest along the edge of the continental shelf (Figure 15). Areas with high species richness (for all demersal fish species) tended to be in water less than 200 m (Figure 16). Areas with high species diversity (for all demersal fish species) tended to be on the slope in waters deeper than 300 m (Figure 17).
- **General Classification of California Marine Fishes.** Allen and Pondella (2006) provided H' (diversity) for 36 marine habitat types and for 14 major marine habitats in California. The middle shelf (Shelf I & II) in the central region had the lowest species diversity recorded in the comparison (H` = ~0.6). The outer shelf (Shelf II) in the central region had a higher diversity of ~1.75, though this value is much lower than most habitats in the study.

- **Flatfish** (Vetter et al. 1994). Flatfish diversity was greatest on the outer shelf (12 species, 100-200 m). After the shelf-slope transition, flatfish diversity decreased rapidly.
- **Demersal Rockfishes off California** (Williams and Ralston 2002). Rockfish richness was highest at a depth of 200-250 meters, where shelf and slope faunal groups overlap. The area between Monterey Canyon and the Mendocino Escarpment - an area of overlap of southern and northern assemblages - was found to have the highest species richness. For southern latitudes (34.0–38.0°N), the ridge of high diversity veered well offshore to a depth of 450 m, and there was some indication of a secondary increase in diversity at 150 m for the most southerly latitudes 34.0–36.0°N.

Biomass: The biomass of infaunal invertebrates appears to be elevated at mid-shelf depths. Biomass of megafaunal invertebrates and fishes appears to be lower on the shelf than on the slope. The biomass of many species of invertebrates and fishes has been reduced, dramatically for some species, by commercial and/or recreational harvest.

- **Infauna near Davenport** (John Oliver, MLML, unpubl. data). In northern Monterey Bay and off Davenport, the mean biomass per sample was highest at 60 m. Mean biomass was elevated at 60-109 m and at 325, 700, and 1500 m.
- **Infauna off Pillar Point** (Kogan et al. 2006). Infauna were surveyed along a submarine cable between Pillar Point and Pioneer Seamount in the northern portion of MBNMS. Biomass was not reported in this study, but estimates of abundance (the average number of infauna per sample) show that infaunal species were more abundant at three (43, 67, 140 m) of the four stations on the shelf (Figure 14). Infauna was less abundant at 75 m and at all the stations on the slope.
- **Fish and Megafaunal Invertebrates in the Gulf of the Farallones** (SAIC and MLML 1992). The highest density of fishes was collected on a mid-depth transect (128m), due primarily to the presence of flatfishes and shortbelly rockfish. Shelf depths had lower biomass than upper and middle slope depths. Megafaunal invertebrate densities were more variable than fishes; middle slope depths had the highest densities, associated primarily with echinoderms.
- **Demersal Fishes at Point Lobos** (Anderson and Yoklavich 2007). Biomass was not calculated for this study, but density of demersal fishes was provided for three different benthic habitat strata (hard, mixed, soft). The mixed stratum (862 fishes/1000 m^2) had substantially higher density of all demersal fish compared to the soft stratum (130 fishes/1000 m^2), although the density of large-bodied (>20 cm) fish was higher in the soft stratum (21 fishes/1000 m^2) compared to mixed (4 fishes/1000 m^2). The hard stratum appears to have the highest demersal fish biomass based on density estimates for both all demersal fishes (1,357 fishes/1000 m^2) and large-bodied fishes (27 fishes/1000 m^2).
- **Herring** (Hay and McCarter 1997). The Pacific herring life history is closely associated with the continental shelf (<200 m) and adjacent coastal areas. In general, throughout the Northern Hemisphere, areas with large herring populations have broad continental shelves, and areas with small populations have narrow shelves. The density-independent maximal biomass of each stock was estimated based on the availability of shelf area. The maximal average density of herring on the shelf was estimated to be about 10 g/m^2.

- **Harvested Species:** Recreational and commercial harvest removes biomass of targeted fish and invertebrate populations. For some targeted species, biomass is substantially reduced compared to unfished biomass levels (Tables 3 and 4). Though extraction is the primary reason for a reduction in biomass for many species, changing oceanographic and ecological conditions are an important contributing factor for some harvested species. For the majority of the 10 invertebrate and 156 fish stocks landed in MBNMS, the status of the stock has not been assessed (Tables 3 and 4).

MOVEMENT AND DISPERSAL

Due to the lower habitat complexity and patchier food availability in soft bottom habitats, many species commonly found in this habitat may have to move more to find food and avoid predation than species living in rocky habitats (Lowe and Bray 2006). Many species of fish that are found on the sandy shelf during one (or more) life stage(s) also use adjacent habitats during another life stage or during certain times of year. Some examples of these ontogenetic and seasonal movement patterns were summarized by Cailliet et al. (2000):

- **Plainfin Midshipman**: Males migrate inshore in winter to make nests on hard substrates in nearshore (<30 m) and intertidal habitats. Females follow soon after. Both sexes return to deep-water soft-bottom habitats in fall.
- **Flatfish** (e.g., California halibut, starry flounder, rock sole and sand sole): Adults of many species of flatfish move inshore in late winter-early spring to spawn and then move back offshore into deeper water in the summer or early fall.
- **Elasmobranchs** (e.g., leopard sharks, bat rays, round stingray): Some elasmobranchs exhibit seasonal inshore-offshore movements, congregating in shallow waters, such as estuaries and bays, during the breeding season. Many species of elasmobranchs also exhibit along shore movement patterns over soft bottoms.
- **Flatfish and Elasmobranchs** (e.g., California halibut, English sole, speckled sanddab, leopard sharks, bat rays, round stingray): Juveniles are found in nearshore habitats, including estuaries, and move into deeper water as they mature.
- **Petrale Sole**: Adults move offshore to deeper water in fall and winter to spawn.
- **Dover Sole**: age-1 to age-5 fish move inshore during the summer and fall and return offshore by late fall or winter.
- **Shiner surfperch and pile perch**: Move to shallow waters to mate in spring and deeper waters in the fall/winter.
- **Juvenile Rockfish** (Johnson et al. 2001). Juvenile rockfish that recruited to the soft bottom shelf in Monterey Bay underwent ontogenetic movements to deeper waters, with density and size of fishes increasing with depth over the course of the study.
- **English Sole in Monterey Bay** (Brown 2006). Ontogenetic movement from estuaries to the soft-bottom shelf appears to be an important process for supplying new recruits into the offshore, harvested adult population. In a sample of 47 sub-adult and adult English sole collected from the soft-bottom shelf in Monterey Bay, approximately half were identified as having previously resided in estuaries. This level of estuarine contribution to

offshore adult population is much higher than would be expected based on the relative area of estuarine and nearshore sandy habitats in the region.

SPECIES OF SPECIAL INTEREST

Many of species of special resource management interest are found in the soft-bottom shelf habitats of MBNMS Tables 3-7.

- ***Species Landed in the MBNMS***: Of the 10 invertebrate and 156 fish taxa that are commonly caught and sold in the commercial and/or recreational fisheries of MBNMS (Starr et al. 2002a), 7 invertebrates and 79 fishes taxa occur in soft-bottom, shelf habitats. More landed fish and invertebrates occur in the shallower habitats of Shelf I than Shelf II.
- ***Endangered and Threatened Species****:* There are no known endangered or threatened invertebrate species associated with soft-bottom, shelf habitat. Green sturgeon, which is listed as threatened, is the only endangered or threatened fish species in this habitat. Of the 3 listed seabirds and 10 listed marine mammals, Steller sea lions and sea otters are the only species likely to interact strongly with benthic resources on the shelf
- ***Other At-Risk Species****:* None of invertebrate in the federal waters of MBNMS are listed as 'at-risk'. Four at risk fishes occur in soft-bottom shelf habitats. Of the 11 at-risk seabirds and 9 at-risk marine mammals, only the deepest diving seabird (Pink-footed Shearwater) and marine mammals (sea otters and Steller sea lion) are likely to interact strongly with benthic resources on the shelf.

Additional species of special resource management interest in the soft-bottom shelf habitat include:

- Structure-forming invertebrates, such as sea pens, due to their important ecological role in creating habitat structure and their vulnerability to disturbance from human activities;
- Sooty Shearwaters which reach extremely high densities during the summer, when hundreds of thousands of adults forage for fishes and squid in sanctuary waters after migrating from the southern hemisphere;
- Seabirds (e.g., Common Murres, Rhinoceros Auklets, Brandt's Cormorants) and marine mammals (e.g., harbor seals, harbor porpoise, elephant seals, sea otters) vulnerable to disturbance, injury or death from human activities in the sanctuary such as oil spills and entanglement in fishing gear.

Slope (200-3,000 m) – Hard Substrate

HABITAT OVERVIEW

The seafloor between the continental shelf break (~200 m) and 3,000 m is considered slope habitat. A small portion (3.2%) of the slope in MBNMS is composed of hard bottom habitats (Figure 1). Within the federal study area, hard bottom habitats on the slope comprise approximately 466 km^2, which is 4.24% of the study area (Table 2).

Productivity, biomass, and physical energy in the deep sea (>1000 m) are relatively low, increasing the potential sensitivity of this habitat to human impacts. In addition, diversity is relatively high in the deep sea, making the habitat more sensitive to human impacts (Glover and Smith 2003).

Species that live on the continental slope depend on the downward flux of primary production from surface waters. Organic matter produced on the surface sinks to the seafloor where it is consumed by organisms, decomposed, or buried in sediments. As the decomposing detritus sinks through the water column, it creates a zone of relatively low dissolved oxygen at about 700 m known as the oxygen minimum zone (OMZ; see Oxygen Minimum Zone habitat summary for more information). Below the OMZ, the dissolved oxygen and nutrient content of the water is higher. See Figure 4 for general location of the OMZ in MBNMS.

Organisms that associate with deep, complex habitats are difficult to survey. It is only during the past three decades that species-habitat associations in deep rock habitats have been quantitatively surveyed off central and southern California using occupied research submersibles.

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	No specific Information was found on this topic.
Feeding Ground:	The slope off Point Sur between 600-1,200 m (soft and hard bottom) was identified as an important feeding and spawning ground for a diverse group of fishes, many of which utilize shallower nursery grounds on the shelf (Wakefield 1990).
Spawning Ground:	See page 43
Migratory Corridor:	See “Movement and Dispersal” section below for information on species that move to the slope during ontogenetic migrations.
Biogenic Habitat:	See page 44
Energy Flow:	
Primary Production:	See page 46
Benthic-Pelagic Coupling:	See page 46
Key Trophic Interactions:	No specific Information was found on this topic. See “Shelf I &

	II – Hard Bottom” habitat summary for information on the role of detritivores and planktivores on deep reef habitats.
Key Trophic Cascades:	No specific Information was found on this topic.
Productivity Hotspots:	See page 46
HABITAT STRUCTURE	
Species Composition:	See page 47
Species Composition Shifts:	See page 48
Species Diversity and Richness:	See page 49
Biomass:	See page 50
Key Species Interactions	See page 50
MOVEMENT AND DISPERSAL	See page 51
SPECIES OF SPECIAL INTEREST	See page 51

HABITAT SUMMARY

<u>HABITAT FUNCTION</u>

Functional Habitats

Spawning Ground: Slope habitats (soft and hard) in central California are important spawning areas for groundfishes, including those of commercial importance. Rocky outcrops between 1,300-3,000 m (north of the study area) are spawning grounds for blob sculpin and octopus. Similar habitats within the study area may be equally important to these species.

- **Groundfish** (Wakefield 1990). The slope off Point Sur (600-1,200 m) was identified as an important feeding and spawning ground for a diverse group of fishes, many of which utilize shallower nursery grounds on the shelf.
- **Longspine Thornyhead** (Wakefield 1990; Wakefield unpubl. data). Off Point Sur, 93% of the longspine thornyhead spawning stock inhabit 500-1,100 m.
- **Thornyheads** (Jacobson and Vetter 1996). Peak spawning biomass for both thornyhead species off Oregon and central California (Point Sur to Point Conception) occurs between 600-1,000 m. Small shortspine thornyheads are found on the shallow slope (200-600 m), but migrate to deeper water with growth. Longspine thornyhead of all size classes were found between 600-1,400 m.
- **Blob Sculpin and Octopus**. Off northern California (Gorda Escarpment) between 1300-3000 m, Drazen et al. (2003) observed concentrations of blob sculpin (*Psychrolutes phrictus*) and octopus (*Graneledone* spp.) at the crest of steep, rocky outcrops and near cold seeps. Observations were only made during summer months. Biomass of blob sculpin at one site was equivalent to the average total biomass of fishes on the slope. Likewise, density of *Graneledone* was considerably greater than previous estimates. The authors hypothesized that local topography interacting with physical and geological

settings create a localized reproductive hot spot in the deep sea used by at least two very different animals. In a separate study at Cascadia Basin (2,600 m), Voight and Grehan (2000) document that the octopuses *Graneledone* and *Benthoctopus* attached their eggs to basalt outcrops and apparently brood them through development. The dense aggregations of *Graneledone* and *Benthoctopus* may be due to the availability of rocky substrate for egg attachment and bivalve prey from nearby cold seeps.

Biogenic Habitat: Various types of structure-forming invertebrates attach to hard substrates on the slope creating biogenic habitat. Structure-forming organisms contribute significantly to benthic habitat structure and function by adding vertical relief, increasing the diversity of microhabitats, and increasing the surface area for settlement and retention of other organisms. Managed fish species associated with structure-forming invertebrates include: lingcod, longspine and shortspine thornyhead, sablefish, spotted ratfish, and rockfishes (e.g., bocaccio, cowcod, flag, greenspotted, quillback, rosethorn, sharpchin, starry, tiger, vermillion, yelloweye, and yellowtail) (NMFS 2005, Tissot et al. 2006). Structure-forming invertebrates are susceptible to damage from physical structures dragged across the seafloor including anchor lines and fishing gear. Growth rates for many of these invertebrate species are low, extending the time to recovery if these communities are damaged.

- **Structure-forming Invertebrates in MBNMS** (MBARI VARS database 2011). The locations where Monterey Bay Aquarium Research Institute (MBARI) scientists have observed structure-forming invertebrates associated with hard substrates are shown in Figure 8. These observations of gorgonians, stony corals, black corals, hydrocorals, crinoids and sponges were made during ROV surveys in 1989-2009. Each data point represents a sighting regardless of the abundance of the organisms in the video frame. It is important to note that these organisms are likely to occur in portions of MBNMS that have not been sampled by MBARI.

- **Structure-forming Invertebrates Observed in MBNMS Shelf Characterization Surveys** (IfAME and MBNMS 2011). Video transects using a remotely operated vehicle (ROV) and a towed camera sled were made to characterize the distribution of fishes, invertebrates, and seafloor habitats on the continental shelf (50-200 m) and upper slope (200-400 m) at five locations in MBNMS: Ascension and Año Nuevo Canyons; North Monterey Bay; Carmel Bay and Point Lobos; Point Sur Shelf; and La Cruz Canyon and Point Piedras Blancas. Transects covered a varied of substrate types including rock ridges, bolder, and cobble. Structure-forming species commonly observed in this study include brachiopod beds, plumose anemones (*Metridium farcimen*), sponges, basket stars, crinoids, and gorgonians. Specific locations where structure-forming invertebrates were observed along the transects are available through the Shelf Characterization and Image Display website (http://sep.csumb.edu/ifame/scid).

- **Structure-forming Invertebrates in Central California MLPA MPAs** (Starr and Yoklavich 2008). A manned submersible was used to characterize the benthic habitat and associated invertebrates in the deep portion (24-365 m) of eight of the new central California Marine Life Protection Act marine protected areas and associated reference sites. Structure-forming species associated with hard bottom (e.g., corals, sponges, crinoids, gorgonians) were observed at all sites. See Table 9 for a summary of locations where structure-forming species were part of the dominant megafaunal invertebrate assemblage.

- **Deep-sea Corals Collected in Bottom Trawls in MBNMS** (Curt Whitmire, pers. comm.). The locations where deep-sea corals were collected incidentally in bottom trawl surveys by the National Marine Fisheries Service (1980-2010) are shown in Figure 9. Records represent the presence of a given taxonomic group in the area swept by trawl gear; exact location, species, and abundance information is not available. Corals from the following taxa likely were associated with hard substrate: Antipatharia (black corals), Alcyonacea (soft corals), Anthoathecata, Scleractinia (stony corals), and Gorgonacea (gorgonians). It is important to note that these trawl surveys were designed to monitor groundfish populations (not corals) and the surveys occurred mostly over low-relief, soft bottom. Trawl gear is not designed to sample the habitats in which many coral taxa reside, particularly those habitats characterized by rocky substrate and high relief.
- **Deep-sea Coral Distribution** (Etnoyer and Morgan 2003, Morgan et al. 2005). Records on 8 habitat forming deep-sea coral families from 10 different institutions were gathered to create a dataset of range and distribution of corals along the west coast of North America. Habitat-forming deep-sea corals (octocorals, hexacorals, hydrocorals in the Phylum Cnidaria) were defined as those families with a majority of species exhibiting a complex branching morphology and sufficient size to provide substrate or refuge to associated species. The shelf break along the west coast and Monterey Canyon were identified as areas of highest occurrence of deep-sea corals. Examples of species associated with corals include: crabs and fishes (resting/refuge), fish egg cases (attachment substrate in well-aerated water column), and crinoids, basket stars, and anemones (suspension feeding).
- **Deep-sea Coral Habitat Suitability** (Guinotte and Davies 2012). The potential distribution of deep-sea corals was modeled for the U.S. West Coast Exclusive Economic Zone. Predicted habitat suitability in MBNMS is shown separately for 6 deep-sea coral taxa (Figure 10). Habitat suitability probabilities and areal extent of predicted habitat were highest in the sanctuary for Suborders Alcyoniina, Calcaxonia, Holaxonia, and Order Scleractinia. In contrast, suitability probabilities and areal extent were lower in these areas for Order Antipatharia (except at Davison Seamount) and Suborder Scleraxonia. The models used a variety of physical, chemical and environmental variables known or thought to influence the distribution of deep-sea corals. However, the model will likely overpredict the amount of suitable habitat in some areas (e.g., indicate suitable coral habitat in areas that are known soft bottom regions) because fine-scale bathymetric features (10’s of meters), substrate, and current data were not available for the entire study area.
- **Megafaunal Invertebrates on Cordell Bank** (Pirtle 2005). Megafaunal invertebrates and demersal fishes were surveyed at depths between 52 and 365 m at Cordell Bank in 2002 using a submersible. Nineteen species of megafaunal invertebrates, such as sponges, gorgonian corals, crinoids, and large anemones, were identified as structure-forming based on large size, complex morphology, or the ability to form high density aggregations. Several species of fish were observed in close proximity to structure-forming invertebrates. These associations appeared to be especially important in habitats lacking large structural relief or complexity, and were presumably important to smaller fishes in exposed habitats.

Energy Flow

Primary Production: The amount of sunlight needed to support primary production through photosynthesis only penetrates the top 30-50 m of the water column in MBNMS (Rigsby 1999a). Therefore, phytoplankton are a source of primary production in the surface waters over the slope, but photosynthesis cannot occur in the benthic habitats of the slope. In areas where there is seepage of sulfide- and methane-rich fluids, some organisms fix carbon through chemosynthesis. These areas, called “Cold Seeps” or “Chemosynthetic Biological Communities” (CBCs), are the only sources of primary production in the deep-sea habitats of MBNMS and act as oases in an otherwise low productivity area. See “Chemosynthetic Biological Communities” habitat summary for additional information**.**

Benthic-Pelagic Coupling: Deep-sea benthic processes are often tightly linked, or coupled, to particulate-organic flux from the pelagic realm. Coupling occurs because the deep sea is highly dependent on sinking food material (Glover and Smith 2003). The quality and quantity of sinking food materials varies spatially and temporally across the ocean surface on seasonal, interannual, and decadal time scales (Glover and Smith 2003). The buoyant eggs of demersal fishes and invertebrates provide one form of upward flux of particulate organic carbon (POC). Most of the research on measuring flux of organic matter to the benthos occurs in areas with soft bottom; see “Slope – Soft Bottom” and “Submarine Canyon” habitat summaries for specific information on these studies. See “Appendix III - Benthic-Pelagic Coupling” for more general information.

Productivity Hot Spots: Productive areas in slope habitats tend to be dynamic in space and time and, although they can last for decades, they are considered temporary and sometimes unpredictable.

- **Steep Rocky Outcrops and Cold Seep Habitats.** Drazen et al. (2003) observed some of the highest fish and octopus densities ever reported in the deep sea (Gorda Escarpment, N California; 1,300-3,000 m), with most individuals of both species observed brooding eggs. The blob sculpin (*Psychrolutes phrictus*) and octopus (*Graneledone* spp.) were concentrated at the crest of the local topography and near cold seeps where they may benefit from enhanced current flow and local productivity. The authors hypothesize that local topography interacting with physical and geological settings create a localized reproductive hot spot in the deep sea used by at least two very different animals. These findings provide new information on the reproductive behaviors of deep-sea animals. More importantly, they highlight how physical and bathymetric heterogeneity in the environment can result in reproductive hot spots, which may provide a critical resource for reproductive success in some deep-sea species.
- **Edges of the Oxygen Minimum Zone** (Mullins et al. 1985, Thompson et al. 1985). Off central California, the edges of the OMZ may be sites of increased biological activity because of greater nutrient concentrations plus larger food supplies in the form of bacteria. See “Oxygen Minimum Zone” habitat summary for details and Figure 4 for the general location of the OMZ in central California.

- **Whale Falls** (Smith and Baco 2003, Lundsten et al. 2010). Dead whale carcasses that sink to the deep seafloor introduce a massive pulse of energy capable of hosting dynamic communities of organisms in an otherwise food-limited environment. Carcass degradation occurs sub-decadally.

HABITAT STRUCTURE

Species Composition: Invertebrates and fishes are the numerically dominant animal groups on the slope. Few species composition studies have been conducted in deep, rocky habitats. Invertebrates and fishes tend to be distributed by depth, substrate type, and degree of relief.

- **Epifaunal Invertebrates in Northern Monterey Bay** (CSLC & MBNMS 2005). Epifauna were surveyed on hard-bottom habitats 150-1,000 m deep in northern Monterey Bay. The species assemblages were characterized as follows:
    - Outer shelf/upper slope (150-300 m): erect sponges, anemones (e.g., *Stomphia*, *Amphianthus*, *Metridium*), decapods, brittlestars, and sea stars;
    - Middle slope (300-1,000 m): the typical species assemblage has a greater diversity and size of sponges and echinoderms than that observed on the shelf;
    - Many echinoderm genera (e.g., *Florometra, Gorgonocephalus, Strongylocentrotus*) were distributed over a broad depth range (100-500 m or more);
    - High relief (>1m) rocky habitat: suspension feeding cnidarians (e.g., *Allopora*, cup corals, anemones, zoanthids), erect sponges, crinoids (e.g., *Florometra*), basket stars (e.g., *Gorgonocephalus*), and bryozoans;
    - Low relief rocky habitat: species that can survive episodic sediment burial and high suspended particle loads in the water column. Species include anemones (e.g., *Metridium*), cup corals, and brittlestars.
- **Deep-sea Corals** (Etnoyer and Morgan 2003, 2005): Five families of habitat-forming deep-sea corals have been observed in MBNMS: Antipathidae, Paragorgiidae, Primnoidae, Stylasteridae, and Isididae.
- **Megafaunal Invertebrates in the MBNMS** (Graiff 2008). The abundance and distribution of megafaunal invertebrates on the upper slope was surveyed at two sites in the MBNMS using a manned submersible. See Table 8 for the relative abundance of megafaunal invertebrates at Portuguese Ledge (71-252 m) and Big Creek (19-249 m**)**.
- **Megafaunal Invertebrates and Fishes in central California MLPA MPAs** (Starr and Yoklavich 2008). A manned submersible was used to characterize the benthic habitat and associated megafaunal invertebrate and fish assemblages in the deep portion (24-365 m) of eight of the new central California Marine Life Protect Act marine protected areas and associated reference sites. See Table 9 for a summary of the dominant megafaunal invertebrates and the relative abundance of common groups of demersal fishes at each site.

- **Fishes over Hard Substrate** (Love and Yoklavich 2006). In central and northern California the following species make up the typical adult fish assemblage over rocky substrate on the upper slope (201-500 m): aurora, bank, blackgill, bocaccio, chilipepper, cowcod, darkblotched, greenblotched, greenspotted, Pacific Ocean Perch, rosethorn, sharpchin, and splitnose rockfishes and lingcod.
- **General Classification of California Marine Fishes** (Allen and Pondella 2006). The authors used cluster analysis of species assemblages to determine which species occur together and in what habitat (by substrate type, depth, and latitude). The following species assemblages occur over hard bottom slope habitats in central California:
    - **Deep shelf, bank and slope** (>200 m): spiny dogfish, Pacific hake, spotted ratfish, splitnose rockfish, Pacific hagfish, rex sole, longnose skate;
    - **Deep bank and shelf** (>200 m): sablefish, aurora rockfish, blackgill rockfish, brown cat shark, shortspine thornyhead, filetail catshark;
    - **Deep-water generalists**: shortspine thornyhead, spotted ratfish, bank rockfish, shortspine combfish, Pacific hake, swordspine rockfish, greenstriped rockfish, greenblotched rockfish, stripetail rockfish, splitnose rockfish, bocaccio, lingcod. These generalists tended to be equally represented in deep-water habitats with both rocky and soft substrate.
- **Rockfishes** (Love et al. 2002). The typical rockfish assemblages along the coast of central and northern California were identified for five depth categories (Table 10). The species included occur over hard and soft bottom, but the majority of the species are primarily found over hard bottom. Fifteen rockfish species typically occur in slope habitats. Shelf I and Shelf II were the depth categories with the highest species richness - 23 and 22, respectively.
- **Seabirds and Marine Mammals** (Research Planning Inc. 2006). Table 12 provides a list of the seabird and mammal species typically observed along the central California coast and their relative abundance and seasonality in eight pelagic zones off of central California (Figure 12)**.** None of the seabird species dive deep enough to forage on benthic resources on the slope. However, deep diving mammals (e.g., sperm whales, northern elephant seal) can exceed depths of 1,000 m to forage on demersal fishes and invertebrates on the slope.

Species Composition Shifts:

- **Natural Changes**: Significant natural changes in water temperature and current patterns, such as El Niño/La Niña events and the Pacific Decadal Oscillation, can cause shifts in species composition of the rocky slope. Food falls and periods of high productivity in surface waters deliver natural supplies of food to the slope, which in turn can rapidly change the species compositions at these depths.
    - **Whale Falls** (Smith and Baco 2003, Lundsten et al. 2010). Falls of large whales are a sporadic source of large-volume labile organic matter to the deep seafloor. Whale carcasses in the deep ocean off California may pass through three to four overlapping successional stages. In Monterey Canyon, this successional process occurs rapidly; less than 10 years. The majority of species observed at Monterey Canyon whale falls

are common deep-sea inhabitants of Monterey Canyon, nearby seamounts, and the continental slope. See “Slope – Soft Bottom” habitat summary for additional information.

- **Human-induced Changes**: Human activities, such as high levels of fishing, bottom-tending fishing gears, and deposition of marine debris, can influence species composition on in slope habitats.
  - **Fishing Impacts on Fishes**. Intense recreational and commercial fishing can lead to changes in fish assemblages. Levin et al. (2006) found that the fish assemblage on the shelf and upper slope has changed from rockfish dominated in 1977 to flatfish dominated in 2001.
  - **Marine Debris** (Watters et al. 2010). Video surveys in central California found that demersal marine debris altered seafloor habitat and species assemblages by providing artificial habitat to demersal organisms. In surveys during the 1990s, 13% of debris items had fishes associated with them, and 38% were associated with large, structure-forming invertebrates. In 2007, less than 10% of debris items had fishes associated with them, and 30% were associated with large, structure-forming invertebrates. The majority of debris (e.g., 99% of 815 items surveyed in 2007) was colonized moderately to heavily by encrusting invertebrates. Fishes associated with debris that could provide structure and cover; they did not associate with monofilament line. Debris occurred disproportionately in rock compared to soft sediment habitats.
  - **Structure-forming Invertebrates**: Structure-forming invertebrates are very susceptible to damage from gear contacting the seafloor including anchors, chains, nets, pots/traps, trawls and other types of fishing gear (NRC 2002, Chuenpagdee et al. 2003). Due to low growth rates for some structure-forming species (e.g., corals, sponges), these communities can take decades to recover if damaged.

Species Diversity and Species Richness: Species diversity in the deep sea is greater than once thought. Small patches (mm to m) of biogenic disturbance and food input, separated on spatial scales of meters to km, are important in maintaining high diversity in deep-sea communities. Low productivity, reduced broad-scale disturbance, and the large surface area of the deep sea are relevant to the maintenance of diversity. Because of the large surface area and the many undescribed species, diversity in the deep sea may rival that found in tropical rain forests (reviewed in Grassle 1989). High diversity makes this habitat sensitive to human impacts (reviewed in Glover and Smith 2003).

Species diversity of macro- and megafauna in the deep sea follows a parabolic pattern along depth gradients, increasing with depth below the continental shelf to a maximum at mid to lower bathyal regions and then decreasing with increasing distance seaward on the abyssal plain (Rex 1981). The level of diversity in the deep sea may be related to productivity, competition, and predation, and the relative importance of these factors varies with depth.

- **Demersal Fishes off Central California** (NCCOS 2003). Rockfish species richness tended to be highest along the edge of the continental shelf (Figure 15). Areas with high species richness (for all demersal fish species) tended to be in water less than 200 m (Figure 16). Areas with high species diversity (for all demersal fish species) tended to be on the slope in waters deeper than 300 m (Figure 17).

- **Whale Falls.** Local species diversity (mean of 185 macrofaunal species) on large whale skeletons during the sulphophilic stage is higher than in any other deep-sea hard substratum community (Smith and Baco 2003). Global species richness on whale falls (407 species) is also high compared with cold seeps and rivals that of hydrothermal vents (469 species worldwide). The majority of species at Monterey Canyon whale fall communities are common deep-sea inhabitants of Monterey Canyon, nearby seamounts, and the continental slope (Lundsten et al. 2010). Upon initial arrival, whale carcasses host a relatively low-diversity community of mobile scavengers. Through time, diversity increases; however, most of the increases in species richness come from background taxa that exploit abundant nutrients provided by the carcass.

***Biomass*:** Productivity, biomass, and physical energy in the deep sea (>1,000 m) are relatively low, increasing the potential sensitivity to human impacts (Glover and Smith 2003). Unfortunately, we know of no slope station off California where the biomass distribution of the total benthic community (megafauna, macrofauna, and meiofauna) has been measured (Smith and Demopoulos 2003). Very little is known about the biomass on hard bottom slope habitats.

- **Longspine Thornyhead off Central California (**Wakefield unpubl. data, Wakefield and Smith 1990). *Sebastolobus altivelis* (longspine thornyhead) represents 25% of the slope-wide standing stock (biomass) of all demersal fishes (Monterey to Point Sur, 400-1,600 m).
- **Harvested Species:** Recreational and commercial harvest removes biomass of targeted fish and invertebrate populations. For some targeted species, biomass is substantially reduced compared to unfished biomass levels (Tables 3 and 4). Though extraction is the primary reason for a reduction in biomass for many species, changing oceanographic and ecological conditions is an important contributing factor for some harvested species. For the majority of the 10 invertebrate and 156 fish stocks landed in MBNMS, the status of the stock has not been assessed (Tables 3 and 4).

***Key Species Interactions*:** Predation is a species interaction for which we have some information specific to the slope habitat. Much is yet to be learned in deep-water habitats.

- **Predation** (Drazen et al. 2001). Macrourid fishes are among the dominant fishes in the deep sea. Many species are large and, in combination with their abundance, are potentially important apex predators in the deep-sea environment. Apex predators play a vital role in many communities by controlling prey populations, exerting selective pressure, and influencing general community dynamics. The two dominant slope dwelling macrourids (*Coryphaenoides acrolepis, Albatrossia pectoralis*) are at the top of the food web on the upper continental slope, and because of their abundance, may exert significant pressure on their prey populations.
- **Competition and Predation**. The intensity of competition varies inversely to predation pressure in the deep sea (reviewed by Rex 1981). Predation becomes less important as a structuring agent on the upper reaches of the slope. Competition among benthic infauna increases with depth on the slope.

MOVEMENT AND DISPERSAL

Many fishes exhibit some degree of ontogenetic shift in space utilization as they mature and the degree of movement or area used by adults may vary depending on species and location. This is particularly true of demersal species of fishes, such as flatfishes, some rockfishes, and wrasses (Lowe and Bray 2006). Most movement studies have been done on shallower water species. Ontogenetic migration (movement to deep water as fish grow and age) occurs in sablefish, Dover sole, shortspine thornyhead, and weakly in longspine thornyhead (see also Hunter et al. 1990; Jacobson and Vetter 1996). See "Movement and Dispersal" in the soft bottom slope section for more specific information.

SPECIES OF SPECIAL INTEREST

Many species of special resource management interest are found in the hard-bottom slope habitat of MBNMS Tables 3-7.

- ***Species Landed in MBNMS***: Of the 10 invertebrate and 156 fish species that are commonly caught and sold in the commercial and/or recreational fisheries of MBNMS (Starr et al. 2002a), 2 invertebrates and 46 fishes are associated with hard-bottom, slope habitats.
- ***Endangered and Threatened Species****:* None of invertebrate species in the offshore habitats of MBNMS are listed as endangered or threatened. None of the 6 endangered or threatened fish species in MBNMS are associated with hard-bottom, slope habitat. Of the 3 listed seabirds and 10 listed marine mammals, Steller sea lions and sperm whales are the only species that have the potential to interact strongly with benthic resources on the slope.
- ***Other At-Risk Species****:* None of invertebrate species in the offshore habitats of MBNMS are considered to be at-risk. Of the 10 known fishes at-risk, 5 are associated with hard-bottom, slope habitat. Of the 11 at-risk seabirds and 9 at-risk marine mammals, Steller sea lions and sperm whales are the only species that have the potential to interact strongly with benthic resources on the slope.

Additional species of special resource management interest associated with the hard-bottom slope habitat are:

- Structure-forming invertebrates, such as corals and sponges, due to their important ecological role in creating habitat structure and their vulnerability to disturbance from human activities.

Slope (200-3,000 m) – Soft Substrate

HABITAT OVERVIEW

The seafloor between the continental shelf break (~200 m) and 3,000 m is considered the slope habitat. A large portion (94.5%) of the slope in MBNMS is composed of soft bottom habitats (Figure 1). Within the federal study area, soft bottom slope habitats comprise approximately 7,598 km^2, which is 69.1% of the study area (Table 2).

North of Point Conception, the slope descends gently from the shelf to a depth of 600 m, forming a plateau (Neighbors and Wilson 2006). The predominant habitat of the upper slope consists of sandy and muddy sediments (Allen 2006). The soft bottom habitat is relatively flat, although there is some micro-relief resulting from water movement (waves, currents) or biological activity (e.g. excavations, burrows, protruding tubes; Allen 2006). The lack of hard substrate for attachment prevents some invertebrates from colonizing soft bottom habitats. In areas with soft bottom, animals live either on the surface or buried in the sediments. Animals may build somewhat permanent tubes and burrows.

The seafloor between approximately 600-1,000 m intersects a portion of the water column where the oxygen concentration is below 0.5 ml/l. The distribution and abundance of benthic fauna are influenced by dissolved oxygen levels, which fluctuate throughout this oxygen minimum zone (see "Oxygen Minimum Zone" habitat section for more information).

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	No information was found indicating that slope habitats off California serve as nursery areas. One study (Pearcy et al. 1977) suggested that Dover and rex sole may use the upper slope region (off Oregon) as a nursery area during early benthic life.
Feeding Ground:	See page 53
Spawning Ground:	See page 53
Migratory Corridor:	See "Movement and Dispersal" section below for information on species that move to the soft bottom slope during ontogenetic migrations.
Biogenic Habitat:	See page 54
Energy Flow:	
Primary Production:	See page 55
Benthic-Pelagic Coupling:	See page 55
Key Trophic Interactions:	See page 57
Key Trophic Cascades:	No specific information was found on this topic.

Productivity Hotspots:	See page 57
HABITAT STRUCTURE	
Species Composition:	See page 57
Species Composition Shifts:	See page 63
Species Diversity and Richness:	See page 66
Biomass:	See page 67
Key Species Interactions	See page 69
MOVEMENT AND DISPERSAL	See page 70
SPECIES OF SPECIAL INTEREST	See page 71

HABITAT SUMMARY

HABITAT FUNCTION

Functional Habitats

Feeding Ground: The slope habitat off Point Sur is an important feeding ground for a diverse group of demersal fishes (Wakefield 1990). Whale falls provide significant sources of organic material for mobile scavengers in deep-sea habitats. These falls, however, are unpredictable in space and time.

- **Whale Falls** (Smith et al. 1989; Goffredi et al. 2004; Lundsten et al. 2010). It is estimated that hundreds of gray whales sink to the seafloor annually within a $8x10^5$ km^2 area of the North Pacific (along the migration route). This estimate suggests that large animal falls are a significant source of organic enrichment to deep-sea habitats and act as important feeding grounds for mobile scavengers. Carcass degradation at Monterey Canyon occurs sub-decadally.

Spawning Ground: The soft slope between 300-1,200 m has been identified as an important spawning area for a variety of groundfish species.

- **Groundfish** (Wakefield 1990). The slope off Point Sur (600-1,200 m) was identified as an important feeding and spawning ground for a diverse group of fishes, many of which utilize shallower nursery grounds on the shelf.
- **Longspine Thornyhead** (Wakefield 1990; Wakefield unpubl. data). Off Point Sur, 93% of the longspine thornyhead spawning stock inhabit 500-1,100 m.
- **Thornyheads** (Jacobson and Vetter 1996). Peak spawning biomass for both thornyhead species off Oregon and central California (Point Sur to Point Conception) occurs between 600-1,000 m. Small shortspine thornyheads are found on the shallow slope (200-600 m), but migrated to deeper water with growth. Longspine thornyhead of all size classes were found between 600-1,400 m.

- **Dover Sole** (Hunter et al. 1990). Ninety-eight percent of the spawning biomass of Dover sole (*Microstomus pacificus*) in central California waters live on the soft-bottom slope between 640-1,005 m. Dover sole spawn at these depths and the eggs rise to the surface layers.
- **Petrale Sole** (Airamé et al. 2003). Spawning aggregations of petrale sole occur at depths of 300-400 m off Cape Mendocino, Point Delgado, Point Montara, and Point Sal.
- **Giant Grenadier** (Novikov 1970). Male and female giant grenadier (*Albatrossia pectoralis*) live separately (females prefer ~300-700 m; and males prefer >~700 m). This separation is rarely disturbed. During spawning, females migrate to deeper depths (depths may be specific to the North Pacific). The spawning period for giant grenadier is prolonged and not confined to definite dates.

Biogenic Habitat: Though structure-forming invertebrates tend to be more abundant on hard substrate, some species (such as sea pens, sea whips, and brittle stars) are found primarily in soft sediments. In general, these invertebrates provide some of the only emergent structural relief to the surface of soft-bottom habitats, especially when they aggregate in high numbers. Aggregations may provide significant structural relief for fishes in mud- and sand-dominated habitats (Tissot et al. 2006). Structure-forming invertebrates are susceptible to damage from physical structures dragged across the seafloor including anchor lines and fishing gear. Growth rates for many of these invertebrate species are low, extending the time to recovery if these communities are damaged.

- **Sea Pen Observations in MBNMS** (MBARI VARS database 2011). The locations where Monterey Bay Aquarium Research Institute (MBARI) scientists have observed sea pens (Order Pennatulacea) are shown in Figure 13. These observations were made during ROV surveys 1989-2009. Each data point represents a sighting regardless of the abundance of the organisms in the video frame. Sea pens can be fairly abundant on the seabed, so the map generally reflects where sampling has occurred. It is important to note that these organisms are likely to occur in portions of MBNMS that have not been sampled by MBARI.
- **Deep-sea Corals Collected in Bottom Trawls in MBNMS** (Curt Whitmire, pers. comm.). The locations where deep-sea corals were collected incidentally in bottom trawl surveys by the National Marine Fisheries Service (1980-2010) are shown in Figure 9. Records represent the presence of a given taxonomic group in the area swept by trawl gear; exact location, species, and abundance information is not available. Of the 6 coral taxa collected, sea pens (Order Pennatulacea) are the only taxa associated with soft sediments. Sea pens were the most frequently collected taxa, which is likely due to the fact that the trawl surveys were targeting groundfish in low-relief, soft bottom habitats.
- **Structure-forming Invertebrates Observed in MBNMS Shelf Characterization Surveys** (IfAME and MBNMS 2011). Video transects using a remotely operated vehicle (ROV) and a towed camera sled were made to characterize the distribution of fishes, invertebrates, and seafloor habitats on the continental shelf (50-200 m) and upper slope (200-400 m) at five locations in MBNMS: Ascension and Año Nuevo Canyons; North Monterey Bay; Carmel Bay and Point Lobos; Point Sur Shelf; and La Cruz Canyon and Point Piedras Blancas. Transects covered a varied of substrate types including mud and sand. Structure-forming invertebrates commonly observed in soft-bottom habitat include

sea pens, sea whips, and brittle starts. Specific locations where structure-forming invertebrates were observed along the transects are available through the Shelf Characterization and Image Display website (http://sep.csumb.edu/ifame/scid).

- **Structure-forming Invertebrates in Central California MLPA MPAs** (Starr and Yoklavich 2008). A manned submersible was used to characterize the benthic habitat and associated invertebrates in the deep portion (24-365 m) of eight of the new central California Marine Life Protection Act marine protected areas and associated reference sites. Structure-forming species associated with soft bottom (e.g., sea pens, sea whips, brittle stars) were observed at most sites. See Table 9 for a summary of locations where structure-forming species were part of the dominant megafaunal invertebrate assemblage.
- **Chemosynthetic Biological Communities (CBCs)**: Structure-forming invertebrates found at CBCs are used by other sessile organisms as hard substrate for attachment, and by mobile organisms for shelter and food. CBCs in Monterey Bay have been found most frequently on steep slopes at depths exceeding 550 m (Figure 6). More detailed information can be found in the "Chemosynthetic Biological Communities" habitat section.

Energy Flow

Primary Production: The amount of sunlight needed to support primary production through photosynthesis only penetrates the top 30-50 m of the water column in MBNMS (Rigsby 1999a). Therefore, phytoplankton are a source of primary production in the surface waters over the slope, but photosynthesis cannot occur in the benthic habitats of the slope. In areas where there is seepage of sulfide- and methane-rich fluids, some organisms fix carbon through chemosynthesis. These areas, called "Cold Seeps" or "Chemosynthetic Biological Communities" (CBCs), are the only sources of primary production in the deep-sea habitats of MBNMS and act as oases in an otherwise low productivity area. See the "Chemosynthetic Biological Communities" habitat section for more information**.**

Benthic-Pelagic Coupling: Deep-sea benthic processes are often tightly linked, or coupled, to particulate-organic flux from the pelagic realm. Coupling occurs because the deep sea is highly dependent on sinking food material (Glover and Smith 2003). The quality and quantity of sinking food materials varies spatially and temporally across the ocean surface on seasonal, interannual, and decadal time scales (Glover and Smith 2003). The buoyant eggs of demersal fishes and invertebrates provide one form of upward flux of particulate organic carbon (POC).

- **Sources of Downward Flux:**
    - **Marine Snow** (Rigsby 1999b). Food flows to the deep sea in the form of sinking remains and waste from organisms at the sea surface and in the water column. The amount and type of snow varies with the seasons. Peaks of marine snow follow upwelling productivity in spring and summer; during mass molts of krill; and following nightly surface feeding of vertical migrators (in the form of fecal pellets). For addition information, see "Submarine Canyon" habitat summary.
    - **Particulate Organic Carbon (POC)** (Smith and Demopoulos 2003)**.** Upwelling off California causes high flux of particulate organic carbon (POC) to the slope (~10 g $C/m^2/yr$); shelf and slope waters beneath these upwelling zones frequently are depleted of oxygen as a result of high rates of degradation of POC, and the underlying sediments typically are organic rich. Beneath coastal upwelling sites and within the

OMZ, such sediments may contain 2-18% organic carbon by weight (much higher than continental margins; 1-2%). The primary source of organic matter for California slope assemblages include 1) very small sinking particles, 2) phytodetrital aggregates, 3) sinking carcasses of nekton, and 4) sinking parcels of macroalgae such as kelp). Flux of POC appears to play a dominant role in controlling regional variations in biotic structure, much as temperature and rainfall control ecosystem structure in terrestrial habitats.

  - **Sinking Larvacean Houses**: The abandoned mucous houses of the giant larvacean *Bathychordaeus* are a significant source of rapid carbon transport through the water column to the deep seafloor. Robison et al. (2005) estimated the production rate of 1 sinking *Bathychordaeus* house per day in Monterey Bay to be approximately 5.4 mg of total organic carbon. This number is an underestimate of total flux of giant larvacean houses because there are at least two other species found in Monterey Bay. See “Submarine Canyon” habitat summary for additional information.
  - **Macrophyte Detritus** (Harrold et al. 1998). Macrophyte detritus sinking to the benthos is a source of nutrition for benthic organisms living on the slope. See “Macrophyte Detritus” habitat summary for more information.
  - **Whale Falls** (Lundsten et al. 2010). Dead whale carcasses that sink to the deep seafloor introduce a massive pulse of energy capable of hosting dynamic communities of organisms in an otherwise food-limited environment. Carcass degradation occurs sub-decadally. The majority of species in these communities are background deep-sea taxa.
  - **Downward Transport of Domoic Acid** (Sekula-Wood et al. 2009). The concentration of domoic acid (DA) in surface waters and sediment traps - between 550 and 800 m in depth - were measured off the coast of southern California to study vertical fluxes of DA. This study detected rapid vertical transport of DA-containing *Pseudo-nitzschia* cells to sediments on the soft bottom slope. DA-containing particles appear to persist in the sediments and are available for consumption by bottom feeders and incorporation into benthic food webs.
  - **Vertical Ontogenetic Migration (VOM) by Longspine Thornyhead** (Wakefield and Smith 1990). Longspine thornyheads inhabiting the continental slope off central California (Monterey to Point Sur) were studied as a mechanism for coupling transport of particulate matter between surface waters and the bathyal seafloor (400-1,600 m). At bathyal depths it is unlikely that VOM contributes >1% to the POC flux reaching the deep seafloor.

- **Sources of Upward Flux:** The vast majority of marine organisms (including infaunal and epifaunal invertebrates and demersal fish) release eggs and/or larvae that are pelagic.
  - **Longspine Thornyhead Eggs** (Wakefield and Smith 1990). The upward flux of POC as buoyant eggs of demersal fishes (e.g., thornyheads) could represent a significant portion of the total upward flux.
- **Diel Vertical Migration** (reviewed in Raffaellia et al. 2003). Animals that undertake a diel vertical migration feed in surface waters at night and then carry the food (in their guts) down to depths, usually exceeding 200 m, during the day. These organisms greatly increase

the food supply in mid- and deep-waters. Also, fecal pellets that are voided at depth during the day greatly increase the flux of carbon from the surface to the seafloor. In the Pacific, some 43% of the individuals and 47% of the biomass migrate from below 400 m by day to above this depth at night. It has been estimated that there may be a vertical translocation of almost 109 tons/day throughout the world's oceans.

Key Trophic Interactions: Many of the invertebrates living on the soft bottom slope are either detritivores or planktivores. These organisms play an important role in the slope food web by converting phytoplankton, sinking organic matter and nutrients into slope-associated biomass. Brittle stars act as major links in local food chains.

- **Detritivores** (Hyland 1991). The macroinfaunal communities of the continental shelf and slope in Santa Maria Basin were studied for 2.5 years. The majority of the species found in this study were deposit feeders and relied on ingestion and absorption of organic matter in the sediments for nourishment.
- **Brittle Stars Impact Community Energetics** (Summers and Nybakken 2000). Because of their abundance, feeding behavior, and high activity levels, ophiuroids (brittle stars) are thought to significantly impact energetics and ecology of bathyal soft-bottom communities through the utilization, processing, and redistribution of organic matter at the seafloor. Brittle stars increase bioturbation rates and act as major links in local food chains. Compared to sites on the Farallon slope (1,010 - 3,085 m) and Pioneer Canyon (3,090 – 3,300 m), Monterey Canyon sites (2,300 - 3,300 m) had the highest mean abundance of ophiuroids.

Productivity Hotspots: Productive areas in slope habitats tend to be dynamic in space and time and, although they can last for decades, they are considered temporary and sometimes unpredictable.

- **Whale Falls** (Lundsten et al. 2010). Dead whale carcasses that sink to the deep seafloor introduce a massive pulse of energy capable of hosting dynamic communities of organisms in an otherwise food-limited environment. Carcass degradation at Monterey Canyon occurs sub-decadally.
- **Chemosynthetic Biological Communities** are productivity hotspots in slope, rise, and canyon habitats (Paull et al. 2005a). See "'Chemosynthetic Biological Communities" habitat summary for details and Figure 6 for locations where CBCs have been observed in the Monterey Bay area.
- **Edges of the Oxygen Minimum Zone** (Mullins et al. 1985, Thompson et al. 1985). Off central California, the edges of the OMZ may be sites of increased biological activity because of greater nutrient concentrations plus larger food supplies in the form of bacteria. See "Oxygen Minimum Zone" habitat summary for details and Figure 4 for the general location of the OMZ in central California.

HABITAT STRUCTURE

Species Composition: Invertebrates and fishes are the numerically dominant animal groups on the slope. Species distributions appear to be influenced by many factors including depth, sediment composition, and dissolved oxygen levels. The unique faunal assemblage found in Chemosynthetic Biological Communities is described in the CBC habitat summary.

- **Infauna in Northern Monterey Bay** (CSLC & MBNMS 2005). More than 1,000 infaunal species inhabit soft-substrate shelf and slope areas off central California. Infauna were sampled at multiple stations between 325 and 885 m in northern Monterey Bay. Polychaete worms showed the highest abundance and species richness at most depths. Gammarid amphipods were relatively abundant at all stations and were the most abundant taxa at 640, 770, and 795 m. Oligochaete worms were the most abundant taxa at 885 m. Some of the most abundant taxa by depth were:
  - 325 m: polychaete worms (*Sphaerosyllis ranunculus*), ostracods, caprellid amphipods;
  - 450 m: polychaete worms (*Onuphidae* spp., *Protodorvillea gracilis*, and *S. ranunculus*), brittlestars;
  - 640 m: gammarid amphipods (*Ampelisca unsocalae*, *Lepidepecreum serraculum*, and *Tiron biocellata*), bivalves;
  - 770 m: gammarid amphipods (*Ampelisca unsocalae*, *Photis typhlops*, and *Byblis barbarensi*);
  - 795 m: gammarid amphipods (*Lepidepecreum serraculum* and *Ampelisca unsocalae*);
  - 885 m: Oligochaete worms, polychaete worms (*Cossura pygodactylata*).
- **Infauna near Davenport** (John Oliver, MLML, unpubl. data). In northern Monterey Bay and off Davenport, sediment cores along transects have shown distinct infaunal species assemblages that vary by depth:
  - Upper Slope Group (325-450 m): *Chloeia pinnata*, Onuphidae spp., Oligochaetes, *Tellina carpenteri*, *Decamastus gracilis*, Cirratulidae spp., *Euclymeninae* spp., *Mediomastus* spp., *Huxleyia munita*, *Polycirrus* spp.;
  - Oxygen Minimum Zone Group (700 m): *Byblis barbarensis*, *Ampelisca unsocalae*, *Myriochele gracilis*, *Gammaropsis ocellata*, *Phyllochaetopterus limicolus*, *Lepidepecreum kasatka*, *Photis typhlops*, *Scoloura phillipsi*, Nemertea, *Harpiniopsis epistomata*;
  - Deep-sea Zone Group (1,000-2,000 m): *Aricidea (Acmira) simplex*, *Cirratulidae* spp., *Ampharetidae* spp., *Euclymeninae* spp., *Nephtys cornuta*, *Lumbrineridae* spp., *Actiniaria*, *Aricidea* spp., *Cossura candida*, *Neomediomastus glabrus*.
- **Epifaunal Invertebrates in Northern Monterey Bay** (CSLC & MBNMS 2005). More than several hundred epifaunal species inhabit soft-substrate shelf and slope areas off central California. Epifauna were surveyed from 200 to 885 m in northern Monterey Bay. Sea pens, anemones, crabs and sea stars were common at most stations. The species assemblages were characterized as follows:
  - 280-449 m (adjacent to hard substrate): sea urchin (*Strongylocentrotus fragilis*), sea cucumber (*Parastichopus leukothele*), sea star (*R. californicus*);
  - 450-599 m: dominated by sea pen (*Halipteris californica*), also gastropods, cerianthaid anemones, and anemone (*Liponema brevicornis*);

    - > 600 m: dominated by sea pens (*H. californica* and *Umbellula magniflora*), also Tanner crab (*Chionoecetes tanneri*), gastropods, mesomyarian anemones, cerianthaid anemones, and sea cucumber (*Pannychia moseleyi*).

- **Epifauna and Infauna west of Pillar Point** (Kogan et al. 2006). Quantitative comparisons of biological communities between cable (ATOC) and control sites were made in soft bottom habitats from 43-1,940 m. Differences in abundance between cable and control sites were minor. General changes in the benthos across the central California continental margin were documented.
    - Epifauna: Slope sites characterized by large numbers of *Actiniaria* (anemones), especially on hard substrate (cable);
    - Infauna: Primary taxonomic groups at slope sites were polychaetes, crustaceans, and mollusks (Figure 14 illustrates the taxonomic diversity and abundance of infauna).
- **Benthic Invertebrates 300-1,400 m** (Thompson et al. 1985). The distribution of both infaunal and epifaunal invertebrates off central California (Point Lobos to Point Sur) was examined. A distinct depth zonation in relation to dissolved oxygen levels was observed. See “Oxygen Minimum Zone” habitat summary for more information.
- **Megafaunal Invertebrates in the MBNMS** (Graiff 2008). The abundance and distribution of megafaunal invertebrates on the upper slope was surveyed at two sites in the MBNMS using a manned submersible. See Table 8 for the relative abundance of megafaunal invertebrates at Portuguese Ledge (71-252 m) and Big Creek (19-249 m**)**.
- **Benthic Megafauna west of the Farallones** (Nybakken 1996, Nybakken et al. 1998). Benthic megafaunal invertebrates were sampled on the soft bottom slope (2,300-3,075 m) west of the Farallones and in Pioneer Canyon (Monterey Canyon was not adequately sampled). The benthic invertebrate megafauna were dominated by echinoderms (mostly burrowers) with holothurians (cucumbers), ophiuroids (brittle stars), and asteroids (sea stars) in the upper three ranks. Distribution of megafaunal organisms is highly patchy, especially among surface-dwelling forms. Quantitative analysis of differences between sites and between survey years indicated that the megafaunal associations at the same depth in MBNMS are really quite different at different sites. Results also suggest that there are strong seasonal and yearly differences within the same site.
- **Megafaunal Invertebrates and Fishes in central California MLPA MPAs** (Starr and Yoklavich 2008). A manned submersible was used to characterize the benthic habitat and associated megafaunal invertebrate and fish assemblages in the deep portion (24-365 m) of eight of the new central California Marine Life Protect Act marine protected areas and associated reference sites. See Table 9 for a summary of the dominant megafaunal invertebrates and the relative abundance of common groups of demersal fishes at each site.
- **Invertebrates and Fishes in Abyssal Habitats** (Barry et al. 2004). The typical megafaunal assemblage of abyssal deep-sea communities in the eastern Pacific includes moderate densities of macrourid (*Coryphaenoides armatus*) and zoarcid fishes (*Pachychara* sp.), octopus (*Benthoctopus* sp.), holothurians (*Peniogone* spp., *Staurocucumis abyssorum*, *Scotoplanes globosa*), echinoids (*Cystechinus loveni*, *Aporocidaris milleri*), gastropod mollusks (*Mohina vernalis*), ophiuroids (brittle stars), and a variety of less abundant

species. The infaunal macrofauna assemblage is dominated by tube-dwelling ampeliscid amphipods (*Haploops lodo*), but also includes numerous other crustaceans, polychaetes, mollusks, and cnidarians. Sediment-dwelling meiofauna are abundant, and are dominated by nematodes, flagellates, and amoebae, with lesser densities of ciliates, foraminifera, and other groups.

- **Benthic Fishes and Megafaunal Invertebrates West of Half Moon Bay (**SAIC and MLML 1992**)**. Results of cluster analysis based on density and histogram summaries based on species numbers, density, and biomass, indicated that benthic fish and megafaunal invertebrate communities are distributed primarily by depth, and are independent of study area boundaries. Three communities on the slope were determined:
    - Upper Slope (200-500 m): Fish were common and included Dover sole, rex sole, rockfishes and thornyheads. Megafauna abundances were moderate and included sea stars, brittlestars, and sea cucumbers;
    - Mid-Slope (500-1,200 m): Fishes were common and included thornyheads, Dover sole, rattails, and finescale codling. Megafaunal abundance was high and included Tanner crabs, sea stars, brittlestars, snails, and sea cucumbers;
    - Lower Slope (1,200- >1,800 m): Lower slope fishes were sparse and included rattails, finescale codling, and eelpouts. Megafauna were also sparse and included sea cucumbers, brittlestars, sea stars, and cnidarians.
- **Fishes in Northern Monterey Bay** (CSLC & MBNMS 2005). Less than 100 fish species were observed on soft substrate in the upper and middle slope areas (200-1,000 m) off central California. These include: Dover sole, California halibut, rockfishes (*Sebastes* spp.), Pacific hake, sablefish, and skates.
- **Fish-Habitat Associations at Cordell Bank** (Anderson et al. 2009). Habitat type and the associated fish fauna were surveyed between 52-365 m depth using a manned submersible. Five broad-scale habitat zones were characterized by distinct fish faunas, with depth and habitat composition strong predictors of fish assemblage. The continental slope habitat zone (deep mud, 107–298 m) was characterized by flatfishes, poachers, spotted ratfish, hagfishes, longspined combfish, and a few *Sebastes* species (stripetail, splitnose, and sharpchin rockfishes). The total number of species recorded per habitat zone was highest on the slope due to the occurrences of rare species.
- **Demersal Fishes West of the Farallones** (Cailliet et al. 1992, 1999). The deep-sea demersal fish fauna on the soft bottom slope (2,000-3,300 m) west of the Farallones appeared similar in species composition to the fauna of the eastern Pacific and other deep-water sites around the world. The fish fauna was dominated by families Macrouridae, Zoarcidae, Moridae, and Rajidae and included the following species: skate (*Bathyraja trachura*), spiny eel (*Notacanthus chemnitzii*), lizardfish (*Bathysaurus mollis*), snailfishes (*Paraliparis* spp., *Paraliparis rosaceus*, *Careproctus melanurus*, *Careproctus ovigerum*), cuskeel (*Spectrunculus grandis*), codling (*Antimora microlepis*), grenadier (*Coryphaenoides acrolepis*, *C. armatus*, *C. filifer*, *C. leptolepis*), eelpouts (*Lycenchelys* spp., *Pachycara lepinium*, *Bothrocara* spp.).
- **Rockfishes**, Williams and Ralston (2002) examined rockfish assemblages from southern Oregon to Point Conception using data from NMFS shelf and slope trawls over primarily

soft bottom. Rockfish richness was highest at a depth of 200-250 m, where the shelf and slope meet. Depth and latitude were the main determinants of rockfish assemblages. There were four suggested species assemblages based on distribution, ordination, and partitioning analyses and three of these included slope habitat:

- Nearshore (50-150 m): copper, vermilion, brown, and halfbanded rockfishes;
- Southern shelf (100-250 m; 34°N to the Mendocino Escarpment): bocaccio, chilipepper, cowcod, greenspotted, greenstriped, shortbelly, and stripetail rockfishes;
- Northern shelf (150-250 m; 43°N to Monterey Canyon): canary, redstripe, rosethorn, sharpchin, widow, yelloweye, and yellowtail rockfishes.
- Deepwater slope (200-500 m): aurora, bank, blackgill, darkblotched, Pacific Ocean perch, redbanded, shortspine, and splitnose rockfishes.

NOTE: there was overlap in species assemblages between the Monterey Canyon and Mendocino Escarpment.

- **Flatfishes on Smooth Ridge** (Vetter et al. 1994). Flatfishes undergo species replacements with increasing depth along a transect from 100 m on the shelf down to a depth of 1,400 m on the slope. Flatfish diversity was greatest on the outer shelf with 12 species at 100-200 m. After the shelf-slope transition, flatfish diversity decreased rapidly to ~3 species. At 600 m, Dover sole was the only flatfish. Dover sole and deep-sea sole co-occurred at 800-1,200 m with both species common at the 1,000 m site.
- **Demersal Fishes off Point Sur** (Wakefield 1990). A study of the fish fauna for seven 200-m depth intervals from 400 to 1,600 m at Point Sur found that the upper slope habitat between 600 and 1,200 m contains a diverse array of fishes. Faunal break at 400-600 m, corresponds to a transition between shelf- and slope-dwelling species. The depth distribution of the adult population of a number of fishes (e.g., thornyheads, Dover sole, and sablefish) is centered within the OMZ. See "Oxygen Minimum Zone" habitat summary for more information.
- **Fishes on the California Slope** (Allen 2006, Neighbors and Wilson 2006). Common species of the upper, middle, and lower slope were identified (Table 13).
- **Groundfish Assemblages off U.S. West Coast Slope** (Tolimieri and Levin 2006). Data from trawl surveys along the U.S. west coast at 100 m intervals between 200-1,200 m revealed a strong shift in fish assemblage structure at approximately 500-600 m and a second, more minor shift at 900-1,000 m. These shifts are likely due to temperature changes and are possibly a response to the oxygen minimum zone at 600-1,000 m. Five assemblages were identified based on depth and latitude (Figure 18).
- **Fishes on the Slope in the MBNMS** (Steve Ralston, pers. comm.). The depth distributions of 15 fish species/groups were determined using data from NWFSC slope trawl survey in the years 1999-2006 at sites in the MBNMS. Each species or genus generally fell into one of the following groups (Figure19):
    - **Common above OMZ (200-600 m):** chilipepper, shortbelly, stripetail, splitnose and aurora rockfishes, spotted ratfish, rex sole, and bigfin eelpout;

- **Common above and inside OMZ (200-1,000 m)**: cat sharks, Dover sole, sablefish, shortspine thornyhead
- **Common inside and below OMZ (600->1,000 m):** longspine thornyhead, California slickhead, grenadier

- **Benthic Fish and Invertebrate Assemblages** (Zimmerman 2006). Using the NMFS US west coast bottom trawl survey (55-500 m) data during 1995, 1998, and 2001, three biologically distinct assemblages occurred along the US west coast; shallow, middle, and deep assemblages. Within the MBNMS, the shallow (55-183 m) and deep (367-500 m) assemblages were prominent. The middle depth (184-366 m) was lacking a distinct assemblage; there was a mixing of shallow, deep, or uncertain assemblages.
- **Groundfish Assemblages in Central and Northern California**. Using NMFS groundfish shelf trawl data, NCCOS (2003) identified 10 depth-stratified species assemblages between 62 and 463 m (Table 11). Sampling targeted gently sloping soft bottom on the shelf and shelf break, but some hard bottom was probably encountered (highly sloped rocky bottom was not sampled).
- **General Classification of California Marine Fishes** (Allen and Pondella 2006). The authors used cluster analysis of species assemblages to determine which species occur together and in what habitat (by substrate type, depth, and latitude). The following species assemblage was identified for the soft bottom outer shelf and slope in central California: Dover sole, California slickhead, longspine thornyhead, giant grenadier, black hagfish, California rattail.
- **Benthic Fishes off Oregon, Washington, and central N. Pacific** (Pearcy et al. 1982). Families represented by the most species were Scorpaenidae, Liparidae, Zoarcidae on the slope (400-2,600 m) and Lipariididae, Zoarcidae, Macrouridae on the abyssal plains (2,600-3,050 m). The bathymetric ranges of most species began or ended in three zones of rapid faunal change: 400-900 m, 1,900-2,200 m, 2,800-3,100 m. Species assemblages were characterized as follows:
    - The three species assemblages on the upper-slope (515-2,100 m, 800-2,500 m, 860-1,143 m) were dominated by thornyhead (*Sebastolobus* spp.);
    - The one species assemblage on the mid-slope (800-2,300 m) was dominated by Pacific grenadier (*Coryphaenoides acrolepis*);
    - The two species assemblages on the lower slope-abyssal plain (840-3,900 m, 2,100-5,180 m) were dominated by abyssal grenadier (*Coryphaenoides armatus*).
- **Seabirds and Marine Mammals** (Research Planning Inc. 2006). Table 12 provides a list of the seabird and mammal species typically observed along the central California coast and their relative abundance and seasonality in eight pelagic zones off of central California (Figure 12). None of the seabird species dive deep enough to forage on benthic resources on the slope. However, deep diving mammals (e.g., sperm whales, northern elephant seal) can exceed depths of 1,000 m to forage on demersal fishes and invertebrates on the slope.

Species Composition Shifts:

- **Natural Changes**: Significant natural changes in water temperature and current patterns, such as El Niño/La Niña events and the Pacific Decadal Oscillation, can cause shifts in species composition of the rocky slope. Food falls and periods of high productivity in surface waters deliver natural supplies of food to the slope, which in turn can rapidly change the species compositions at these depths.
  - **Whale Falls** (Smith and Baco 2003, Lundsten et al. 2010). Falls of large whales are a sporadic source of large-volume labile organic matter to the deep seafloor. Whale carcasses in the deep ocean off California may pass through three to four overlapping successional stages:
    - A "necrophage" or mobile-scavenger stage: aggregations of sleeper sharks, hagfish, rattails and invertebrate scavengers;
    - An "enrichment opportunist" stage: organically enriched sediments and exposed bones are colonized by dense assemblages of opportunistic polychaetes and crustaceans;
    - A "sulphophilic" stage: a large, species-rich, trophically complex assemblage lives on the skeleton as it emits sulphide from anaerobic breakdown of bone lipids; this stage includes a chemoautotrophic component deriving nutrition from sulphur-oxidizing bacteria;
    - A "reef" stage: inhabited by suspension feeders exploiting the remaining nutrient-depleted hard substrate.

    In Monterey Canyon, this successional process (without "reef" stage) occurs rapidly; less than 10 years (Lundsten et al. 2010). The majority of species at Monterey Canyon whale fall communities are common deep-sea inhabitants of Monterey Canyon, nearby seamounts, and the continental slope. Bone specialists are abundant and include many species of bone-eating worms *Osedax* sp., and two bone-eating gastropods. The abundance of these bone-eating worms at whale falls suggests they might play a substantial role in the cycling of large organic inputs into the surrounding deep-sea communities (Monterey Bay, 2,891 m). Sub-decadal degradation of whale skeletons appears to be largely driven by *Osedax*. Lundsten et al. 2010 suggest *Osedax* be considered a foundation species that controls whale-fall community structure and longevity.

- **Human-Induced Changes**: A variety of human activities, including the use of bottom-tending fishing gear, laying of submerged cables, disposal of dredge material, deposition of marine debris, and sunken vessels, can alter species composition in slope habitats.
  - **Effects of a Submarine Cable on the Benthic Fauna in Northern MBNMS** (Kogan et al. 2006). The potential impacts of a submarine cable on the distribution and abundance of 17 megafaunal groups and 19 infaunal taxa were investigated using video observations and sediment cores. No cable-related changes in distribution or abundance were detected for most faunal groups. Three megafaunal groups exhibited cable-related changes at one or more stations. Sea anemones colonized the cable when it was exposed on the seafloor, and were therefore generally more abundant on the cable than

in surrounding, sediment-dominated seafloor habitats. Some fishes, such as flatfishes, were more abundant near the cable, apparently due to the higher habitat complexity provided by the cable. Sea cucumbers, a minor element of the seafloor fauna, were less abundant near the cable than along the control transect at one (1700 m station) of the six stations inhabited by this group. These results suggest that the biological impacts of the cable were minor.

- **Effects of Submarine Cable on Seabed and Benthic Faunal Assemblages** (Kuhnz et al. 2011). A geological and biological sampling program was performed to assess the condition of the Monterey Accelerated Research System (MARS) cable and its potential effects on seabed geology and biology. The major conclusion of the study is that the MARS cable has had little detectable impact on seabed geomorphology, sediment conditions, or biological assemblages. Specific conclusions include the following:
  - Changes in mean grain size were undetectable in relation to the MARS cable.
  - The percent organic carbon content of sediments increased near the MARS cable at some locations, possibly due to natural variation or the effects of the cable or both.
  - Local variation in benthic megafaunal communities near (within 50-100 m) the MARS cable is minor or undetectable.
  - The MARS cable has little or no detectable effect on the distribution and abundance of macrofaunal and megafaunal assemblages on a regional scale (e.g. kilometers).
- **Effects of Exploitation on the West Coast Groundfish Assemblage** (Levin et al. 2006). Data from fishery-independent trawls on the soft bottom shelf and slope (55 to 366 m) conducted by NMFS from 1980-2001 along the U.S. west coast (WA, OR, CA combined), indicate that there have been fundamental changes in the fish assemblage. Populations of flatfishes, cartilaginous fishes, and small rockfishes have increased, while populations of large rockfishes have decreased. In 1977, rockfishes were more than 60% and flatfishes were 34% of the fish captured in the survey. In 2001, rockfishes were 17% of the fish captured in the survey and flatfishes were nearly 80%. The species that now dominate the assemblage have vastly different trophic roles and life-history strategies than the species they replaced.
- **Effects of Bottom Trawling on Seafloor Assemblages in Oregon** (Hixon and Tissot 2007). Visual transects over mud seafloors (183-361 m depth) at Coquille Bank, Oregon were used to compare the seafloor assemblages in trawled and untrawled areas. Untrawled seafloors had 23% more fish and 6 times greater density of benthic invertebrates than trawled seafloors. Untrawled seafloors had 27 fish species and 6 taxa of benthic invertebrates compared to 19 species of fish and 11 taxa of benthic invertebrates on trawled seafloors. The seafloor assemblages were characterized as follows:
  - **Untrawled assemblage:** sea pens, ratfish, sablefish, ronquil, slender sole, and poacher. Sea pens, which dominated untrawled bottoms, are sessile, slow-growing, long-lived species that are likely to recover slowly from physical disturbance;

        - **Trawled assemblage:** sea stars, hermit crabs, bigfin eelpout, Dover sole, hagfish, and shortspine thornyhead. These species are known mobile scavengers that may aggregate along trawl-door tracks.
    - **Effects of Demersal Marine Debris** (Watters et al. 2010). Video surveys in central California of the seafloor at depths of 20-365 m observed various type of debris including monofilament line, longlines, nets, traps, beverage cans, bottles, anchors, cables, household items, and construction items. By providing artificial habitat to demersal organisms, debris can alter seafloor habitat and species assemblages. In surveys during the 1990s, 13% of debris items had fishes associated with them, and 38% of items were associated with large, structure-forming invertebrates. In 2007, less than 10% of debris items had fishes associated with them, and 30% were associated with large, structure-forming invertebrates. The majority of debris (e.g., 99% of 815 items surveyed in 2007) was colonized moderately to heavily by encrusting invertebrates. Fishes only associated with types of debris that could provide structure and cover; they did not associate with monofilament line. Though debris occurred disproportionately in rocky habitats, ~40% of debris was observed on soft sediments.
    - **Species Associated with Sunken Vessels in MBNMS.** When a vessel sinks and settles on the soft-bottom slope, they introduce hard substrate into the local area. This hard substrate is colonized over time by a fauna that is more similar to the fauna associated with the hard-bottom slope habitat.
        - **Macrofaunal Invertebrates and Fishes Associated with the Shipwreck of the Oil Tanker *Montebello*** (de Marignac and Burton 2003). The shipwreck of the oil tanker *Montebello* lies on the soft-bottom slope at approximately 275 meters off Cambria (adjacent to the southern border of MBNMS). The wreck is an artificial reef that is teeming with fishes and invertebrates. Sixteen species of fishes and 29 species of macrofaunal invertebrates were identified. The high relief and hard substrate provided by the *Montebello* created habitat for different species assemblages than that of the surrounding low-relief, soft bottom habitat.
            - **Fishes:** Rockfishes were very common. Large schools of bank, bocaccio, chilipepper, and widow rockfish aggregated at the upper part of the shipwreck. Splitnose and greenstriped rockfish were observed at the base of the hull and around the vicinity of the shipwreck. Redbanded and greenblotched/pinkrose rockfish were distributed throughout the shipwreck. The other fish species identified (Pacific hagfish, spotted ratfish, Pacific Argentine, eelpouts, poachers, and Dover sole) were typically observed on the seafloor at the base of the hull and in the vicinity of the shipwreck. The occurrence and abundance of these species were representative for the area, with the possible exception of the higher number of Pacific hagfish.
            - **Macrofaunal Invertebrates:** The white plumed anemone (*Metridium farcimen*) was abundant, especially on the upper area of the shipwreck. Other sessile invertebrates on the shipwreck included vase and encrusting sponges, hydroids, anemones (*Actinostola* sp.), brown cup coral (*Paracyathus stearnsii*) and tunicates (*Clavelina* sp.). Mobile invertebrates observed on and around the shipwreck included at least six species of crustaceans (e.g., Cancer crab,

California king crab, and red galatheid crab, spot prawn), at least five species of sea star, and four species of sea cucumber. Dense patches of a polynoid polychaete (*Chloeia* sp.) and low numbers of white sea pen (*Stylatula elongata*) and California sea slug (*Pleurobranchaea californica*) were recorded on the seafloor around the shipwreck. The abundant fishing gear entangled on the *Montebello* was still catching fish; king crabs and an octopus were feeding on fish caught in the nets.

- **Macrofaunal Invertebrates and Fishes Associated with the Shipwreck of the *USS Macon*** (Burton and Lundsten 2006). The *USS Macon* is located on the soft-bottom continental slope off Point Sur at approximately 430 meters. The wreckage provides hard-bottom habitat for sessile invertebrates, mobile invertebrates, and fishes, serving as an artificial reef in the deep sea. At least 90 taxa were observed at the Macon wreck site and surrounding area. Organisms typically found in deep, hard-bottom habitats were observed at the wreck site, and those typically found in soft-bottom habitats were found in the surrounding areas. There was overlap in species composition at the interface of hard- and soft-bottom habitats (mixed habitats). Four fish taxa were the most abundant organisms at the wreck site: sablefish, Pacific hake, blackgill rockfish, and thornyheads. Common taxa associated with the wreck included anemones, basket stars, and rockfishes. Other common taxa associated with the interface of the wreck and soft-bottom habitats included sea stars, brittle stars, hagfishes, and flatfishes.

Species Diversity and Species Richness: Species diversity in the deep sea is greater than once thought. Small patches (mm to m) of biogenic disturbance and food input, separated on spatial scales of meters to km, are important in maintaining high diversity in deep-sea communities. Low productivity, reduced broad-scale disturbance, and large surface area of the deep sea are relevant to maintenance of diversity. Because of the large surface area and the many undescribed species, diversity in the deep sea may rival that found in tropical rain forests (reviewed in Grassle 1989). High diversity makes this habitat sensitive to human impacts (reviewed in Glover and Smith 2003).

- **Infauna Near Davenport** (John Oliver, pers. comm.). In northern Monterey Bay and off Davenport, the mean number of species in sediment cores increased along the shelf, peaking at 109 and 150 m (at the shelf break), and then declined along the slope to 700 m. The mean number of species per sample was similar from 700-2,000 m. The number of species of crustaceans followed a similar pattern.

- **Megafaunal Invertebrates Inside and Outside Monterey Bay** (Oliver et al. 2011). Estimates of soft-bottom species density were obtained by sampling benthic megafaunal invertebrate communities in four major sampling programs along the coast of Central and Northern California. Three of these programs were focused around the Monterey Bay area. Samples from 30 to 2,000 m depths were analyzed. There were fewer species along the slope – 335 species/m^2 on the upper slope (250-750 m) and 205 species/m^2 from the lower slope (950-2000 m) – as compared to the shelf-slope break (446 species/m^2). Species density was higher inside the bay (328-446 species/m^2) compared to outside (336-339 species/m^2) when comparing samples from the same water depths.

- **Whale Falls**. Local species diversity (mean of 185 macrofaunal species) on large whale skeletons during the sulphophilic stage is higher than in any other deep-sea hard substratum community (Smith and Baco 2003). Global species richness on whale falls (407 species) is also high compared with cold seeps and rivals that of hydrothermal vents (469 species worldwide). The majority of species at Monterey Canyon whale fall communities are common deep-sea inhabitants of Monterey Canyon, nearby seamounts, and the continental slope (Lundsten et al. 2010). Upon initial arrival, whale carcasses host a relatively low-diversity community of mobile scavengers. Through time, diversity increases; however, most of the increase in species richness comes from background taxa that exploit abundant nutrients provided by the carcass.
- **Marine Fishes off California** (Allen and Pondella 2006). Species diversity (H') and species richness (S) are provided for 14 major habitat types in California waters. The deepest major habitats (Deep Slope, Deep Bank and Deep Reef) had some of the lowest species richness (~15, ~16, and ~35 species, respectively). Deep Slope, Deep Bank and Deep Reef varied in their species diversity; ~1.5, ~1.9, and ~2.6, respectively.
- **Demersal Fishes in Central California** (NCCOS 2003). Rockfish species richness tended to be highest along the edge of the continental shelf (Figure 15). Areas with high species richness (for all demersal fish species) tended to be in water less than 200 m (Figure 16). Areas with high species diversity (for all demersal fish species) tended to be on the slope in waters deeper than 300 m (Figure 17).
- **Demersal Fish Species Richness** (Wakefield 1990). A study of the fish fauna on the slope at Point Sur found that the number of species identified from trawls was relatively constant at ~20 species for four 200-m depth intervals from 400 to 1,000 m. Richness decreased below 1,000 m to a minimum at 1,600 m.
- **Flatfish Diversity** (Vetter et al. 1994). Flatfish diversity is greatest (12 species) at the outer shelf (100-200 m). After the shelf-slope transition, flatfish diversity decreases rapidly to approximately 3 species. At 600 m, Dover sole is the only flatfish. Dover and deep-sea sole co-occur at 1,000-1,200 m. At 1,400 m, deep-sea sole abundance declines and no flatfishes occur at deeper depth.
- **Species Diversity in Groundfish Assemblages off U.S. West Coast Slope** (Tolimieri 2007). Patterns of diversity (species richness, species diversity, and evenness) in groundfish assemblages were investigated in relation to depth (100-1200 m) and latitude (33-47°N). Data (pooled across depths) from trawl surveys along the U.S. west coast at 100 m intervals between 200-1,200 m revealed species density and evenness declined with latitude. Latitudinal gradients were examined within four depth zones (200-300 m, 400-500 m, 600-900 m, and 1000-1200 m). At deeper depths (1000-1200 m), species richness and evenness were inversely correlated with latitude. In two shallower categories, species richness and evenness were positively correlated with latitude.

Biomass: Productivity, biomass, and physical energy in deep sea (>1,000 m) are relatively low, increasing the potential sensitivity to human impacts (Glover and Smith 2003). Unfortunately, we know of no slope station off California where the biomass distribution of the total benthic community (megafauna, macrofauna, and meiofauna) has been measured (Smith and Demopoulos 2003).

- **Infauna near Davenport** (John Oliver, pers. comm.). In northern Monterey Bay and off Davenport, the mean biomass per sample was highest at 60 m. Mean biomass was elevated at 60-109, 325, 700, and 1,500 m.
- **Invertebrates off Central California** (Thompson et al. 1985). Polychaetes were the most abundant invertebrate throughout the depth range 300-1,400 m between Point Lobos and Point. Sur. Though populations of large epifauna are rare relative to small infauna, they locally comprise a significant portion of the invertebrate biomass. Specifically, echinoderms constitute >90% of biomass (57 g/m^2) at the upper (500-600 m) and lower (900 m) edges of the oxygen minimum zone. See "Oxygen Minimum Zone" habitat section for additional information.
- **Invertebrates and Fishes** (Smith and Demopoulos 2003). The California slopes and basins harbor rich benthic assemblages:
    - Epibenthic megafauna (>2 cm) often are abundant (densities: 0.3-17 indiv/m^2). Echinoderms are particularly common with brittle stars and holothuroids dominating the megafauna, and at times attaining high biomasses (67+/- 30 g wet wt/m^2). Other taxa include gastropods, hexactinellid sponges, fishes (macrourids, zoarcids, hagfish), decapods and galatheids;
    - Macrobenthos (2 cm-300 µm) consist of a high diversity of taxa, especially polychaetes, agglutinating foraminifera, bivalves, cumaceans, tanaids, and enteropneusts, with biomass of 4-8 g wet wt/m^2 and abundances of 5,000-10,000 individuals/m^2;
    - Meiobenthos (300 µm-42 µm) are an abundant but relatively poorly studied component of the slope benthos. Nematodes, calcareous and agglutinating foraminifera, and harpacticoid copepods abound in this size class, with forams and nematodes probably the most abundant. A small number of core samples (620-3,700 m) found foram biomass ranging from 2.6-1,700 g wet wt/m^2; foram biomass may approach and even substantially exceed that found in the macrofaunal and megafaunal size categories from similar depths;
    - Nanobenthos (<42 µm, including bacteria, Archaea, yeasts, ciliates, flagellates, and amoebae) constitute an important but poorly evaluated component of the slope benthos. Limited studies suggest that California slope sediments harbor microbial biomasses that are high by the standards of both the deep sea and shallower waters.
- **Groundfish off Central California (**Butler et al. 1989, Wakefield unpubl. data). Eight species of demersal fishes (shortspine thornyhead, longspine thornyhead, Dover sole, rex sole, deep-sea sole, sablefish, Pacific grenadier, giant grenadier) dominate the slope in terms of biomass off central California (Half Moon Bay to Purisima Point).
- **Groundfish off Point Sur** (Wakefield 1990). Total fish biomass is constant between 600-800 m (average 24 mt/km^2). Biomass decreased below 1,000 m to a minimum at 1,600 m (4 mt/km^2). Estimates of abundance and biomass for the entire upper slope between 300-1,700 m were 102,700/km^2 and 16.1 mt/km^2, respectively.
- **Longspine Thornyhead off Central California (**Wakefield unpubl. data; Wakefield and Smith 1990). *Sebastolobus altivelis* (longspine thornyhead) represents 25% of the slope-wide standing stock (biomass) of all demersal fishes (Monterey to Point Sur, 400-1,600 m).

- **Thornyheads in Central California** (Jacobson and Vetter 1996). Biomass for both thornyhead species off central California (Point Sur to Point Conception) was determined from trawl survey data. The biomass of shortspine thornyhead was relatively constant across depth strata (400-1,000 m) whereas that of longspine thornyhead peaked sharply at 800–1000 m. Average biomass (kg/km^2) by depth stratum (m) were:
    - Shortspine thornyhead:
        - 200–400 m = 44 kg/km^2
        - 400–600 m = 714 kg/km^2
        - 600–800 m = 531 kg/km^2
        - 800–1000 m = 772 kg/km^2
        - 1000–1200 m = 176 kg/km^2
        - 1200–1400 m = 57 kg/km^2
    - Longspine thornyhead:
        - 200–400 m = 2 kg/km^2
        - 400–600 m = 692 kg/km^2
        - 600–800 m = 1,736 kg/km^2
        - 800–1000 m = 2,775 kg/km^2
        - 1000–1200 m = 216 kg/km^2
        - 1200–1400 m = 81 kg/km^2
- **Groundfish in Eastern North Pacific** (Pearcy et al. 1982). The benthic fish fauna was examined from beam and otter trawl surveys from the slope and abyssal plains off Oregon, Washington, and the central North Pacific (400-5180 m). Abundance and biomass were highest at the slope North Station (515-805 m; 10.7/1000 m^2 and 2.9 g/m^2, respectively) and lowest on the Tufts Abyssal Plain (2,780-2,820 m; 0.6/1000m^2 and 0.2 g/m^2, respectively).
- **Harvested Species:** Recreational and commercial harvest removes biomass of targeted fish and invertebrate populations. For some targeted species, biomass is substantially reduced compared to unfished biomass levels (Tables 3 and 4). Though extraction is the primary reason for a reduction in biomass for many species, changing oceanographic and ecological conditions are an important contributing factor for some harvested species. For the majority of the 10 invertebrate and 156 fish stocks landed in MBNMS, the status of the stock has not been assessed (Tables 3 and 4).

Key Species Interactions: Predation and facilitation are two species interactions for which we have some information specific to the soft bottom slope habitat. Much is yet to be learned in deep-water habitats.

- **Predation** (Drazen et al. 2001). Macrourid fishes are among the dominant fishes in the deep sea. Many species are large and, in combination with their abundance, are potentially important apex predators in the deep-sea environment. Apex predators play a vital role in many communities by controlling prey populations, exerting selective pressure, and influencing general community dynamics. The two dominant slope dwelling macrourids (*Coryphaenoides acrolepis, Albatrossia pectoralis*) are at the top of the food web on the upper continental slope and, because of their abundance, may exert significant pressure on their prey populations.

- **Facilitation**
  - **Brittle Stars Impact Community Energetics** (Summers and Nybakken 2000). Because of their abundance, feeding behavior, and high activity levels, ophiuroids (brittle stars) are thought to significantly impact energetics and ecology of bathyal soft-bottom communities through utilizing, processing, and redistributing organic matter at the seafloor. Brittle stars increase bioturbation rates and act as major links in local food chains. Compared to two other sites (Farallon slope 1,010-3,085 m and Pioneer Canyon 3,090-3,300 m), Monterey Canyon (2,300-3,300 m) had the highest mean abundance of ophiuroids.
  - **Bioturbation** (Smith and Demopoulos 2003). Bioturbation, or the movement of sediment particles by animals, is a key ecosystem process in low-energy, depositional environments, such as much of the deep sea. Bioturbation results from the sum of deposit-feeding, locomotion and home-building activities of the benthos; rates of bioturbation thus provide an integrative measure of the physical activity of sediment assemblages (Pacific Ocean with reference to California slope).
  - **Black hagfish** (Wakefield 1990). The numeric and gravimetric importance of *Eptatretus deani* (black hagfish) in the upper-slope fish assemblage was unexpected. This hagfish represented 25% of the total fish abundance between 300-1,600 m. Due to the abundance and size of burrows excavated by *E. deani*, this scavenger may play an important role in resuspending and reworking sediments and it may have a major influence on the community structure within a portion of the upper slope off central California (Point Sur).

MOVEMENT AND DISPERSAL

Almost all fishes exhibit some degree of ontogenetic shift in space utilization as they mature and the degree of movement or area used by adults may vary depending on species and location. This is particularly true of demersal species of fishes, such as flatfishes, some rockfishes, and wrasses (Lowe and Bray 2006). Most movement studies have been done on shallower water species. Ontogenetic migration (movement to deep water as fish grow and age) occurs in sablefish, Dover sole, shortspine thornyhead, and weakly in longspine thornyhead (see also Hunter et al 1990; Jacobson and Vetter 1996).

- **Sablefish (**Jacobson et al. 2001). Depth range of the smallest individuals was 183-364 m. The largest individuals occurred in the entire depth range, but were relatively rare in the shallowest water and relatively abundant in the deepest water (survey to 1,280 m).
- **Dover Sole and Shortspine Thornyhead** (Jacobson et al. 2001). Depth range of the smallest Dover sole and shortspine thornyhead was 183-547 m. The largest individuals occurred in the entire depth range, but were relatively rare in the shallowest water and relatively abundant in the deepest water (survey to 1,280 m).
- **Dover Sole** (Hunter et al. 1990). Dover sole migrate to deeper depths as they grow, mature, and age. Ontogenetic movement down the shelf to the slope is gradual and occurs over decades.

SPECIES OF SPECIAL INTEREST

Many species of special resource management interest are found in the soft-bottom slope habitats of MBNMS Tables 3-7.

- ***Species Landed in MBNMS*:** Of the 10 invertebrate and 156 fish species that are commonly caught and sold in the commercial and/or recreational fisheries of MBNMS (Starr et al. 2002a), one invertebrate (Dungeness crab) and 47 fishes are associated with the soft-bottom slope.
- ***Endangered and Threatened Species**:* There are no known endangered or threatened invertebrate or fish species associated with the soft-bottom slope. Of the 3 listed seabirds and 10 listed marine mammals, Steller sea lions and sperm whales are the only species that potentially interact with benthic resources on the slope.
- ***Other At-Risk Species**:* None of the invertebrate taxa in the federal waters of MBNMS are considered to be at-risk. Shortspine thornyhead is the only at-risk fish associated with soft-bottom, slope habitat. Of the 11 at-risk seabirds and 9 at-risk marine mammals, Steller sea lions and sperm whales are the only species that potentially to interact with benthic resources on the slope.

Additional species of special resource management interest associated with the soft-bottom slope habitat are:

- Structure-forming invertebrates, such sea pens, due to their important ecological role in creating habitat structure and their vulnerability to disturbance from human activities.

Rise (>3,000 m) – Soft Substrate

HABITAT OVERVIEW

One must dive over 3,000 meters before landing on the seafloor in the central western portion of Monterey Bay National Marine Sanctuary and in portions of the Davidson Seamount Management Zone. The vast majority (~91%) of the seafloor habitat in Monterey Bay National Marine Sanctuary that is deeper than 3,000 m, also known as the rise, is composed of soft bottom habitats (Figure 1). Within the federal study area, soft bottom habitats of the rise comprise approximately 1,720 km^2, which is 15.6% of the study area (Table 2).

The Davidson Seamount is the only known hard-bottom feature in the rise habitat of MBNMS. This inactive volcano is approximately 42 km long and rises 2,300 m off the seafloor. The base is in the rise and the summit is in the slope depth zones. Due to its uniqueness and because it occurs in two benthic habitat zones, the Davidson Seamount is discussed in the "Seamounts" habitat section. Other than the seamount, the rise habitat in the sanctuary is almost entirely soft bottom. Very little is known about the rise habitat and communities.

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	No specific information was found on this topic.
Feeding Ground:	No specific information was found on this topic.
Spawning Ground:	No specific information was found on this topic.
Migratory Corridor:	No specific information was found on this topic.
Biogenic Habitat:	Structure-forming invertebrates found in Chemosynthetic Biological Communities are used by other sessile organisms as a hard surface for attachment, and by mobile organisms for shelter or food. See "Chemosynthetic Biological Communities" habitat summary for additional information.
Energy Flow:	
Primary Production:	In areas where there is seepage of sulfide- and methane-rich fluids, some organisms fix carbon through chemosynthesis. These areas, called "Cold Seeps" or "Chemosynthetic Biological Communities" (CBCs), are the only source of primary production in the deep-sea habitats of MBNMS. See the "Chemosynthetic Biological Communities" habitat summary for additional information.
Benthic-Pelagic Coupling:	See page 73
Key Trophic Interactions:	See page 74
Key Trophic Cascades:	No specific information was found on this topic.

Productivity Hotspots:	See page 74
HABITAT STRUCTURE	
Species Composition:	See page 74
Species Composition Shifts:	See page 75
Species Diversity and Richness:	See page 76
Biomass:	See page 77
Key Species Interactions	See page 77
MOVEMENT AND DISPERSAL	No specific information was found on this topic.
SPECIES OF SPECIAL INTEREST	There are no species of special resource management interest associated with the rise habitat in MBNMS (Tables 3-7). Some deep-water fish species (e.g., grenadiers) might be targeted by fisheries in the future.

HABITAT SUMMARY

<u>HABITAT FUNCTION</u>

Energy Flow

Benthic-Pelagic Coupling (reviewed by Raffaellia et al. 2003). There is a two-way exchange, or flux of matter, between the benthos and the overlying water body, which is important for both benthic and pelagic compartments. This flux occurs through sinking of non-living organic matter (e.g., falling plankton, fecal pellets, animal carcasses, and drift algae) and the active movement of organisms.

- **Particulate Organic Carbon (POC) and Particulate Total Nitrogen (PTN)** (Smith et al. 2001). Fluxes of POC and PTN measured over an and 8-year period via sediment traps 600 m and 50 m above the seafloor at Station M (4,100 m, west of California) declined significantly from October 1989-1996 and then increased in 1998. These flux measurements, when compared to the sediment community oxygen consumption, suggest that there is a food deficit in the deep sea. Sediment traps may have under-sampled flux from lateral advection of organic matter from the slope and shelf and from dissolved organic matter. These sources may explain the discrepancy between supply and demand in the abyssal Pacific. Decadal-scale climate variations influencing marine primary production and terrestrial discharges into the ocean may be extremely important in understanding biogeochemical processes in the deep sea.
- **Whale Falls** (Lundsten et al. 2010). Dead whale carcasses that sink to the deep seafloor introduce a massive pulse of energy capable of hosting dynamic communities of organisms in an otherwise food-limited environment. Carcass degradation occurs sub-decadally. The majority of species in these communities are background deep-sea taxa.
- **Sinking Larvacean Houses**: The abandoned mucous houses of the giant larvacean *Bathychordaeus* are a significant source of rapid carbon transport through the water

column to the deep seafloor. Robison et al. (2005) estimated the production rate of 1 sinking *Bathychordaeus* house per day in Monterey Bay to be approximately 5.4 mg of total organic carbon. This number is an underestimate of total flux of giant larvacean houses because there are at least two other species found in Monterey Bay. See "Submarine Canyon" habitat summary for additional information.

Key Trophic Interactions: Many of the invertebrates living on the rise are either detritivores or planktivores. These organisms play an important role in the food web by converting sinking organic matter and nutrients into benthic-associated biomass. Brittle stars act as major links in local food chains.

- **Brittle Stars Impact Community Energetics** (Summers and Nybakken 2000). Because of their abundance, feeding behavior, and high activity levels, ophiuroids (brittle stars) are thought to significantly impact energetics and ecology of bathyal soft-bottom communities through the utilization, processing, and redistribution of organic matter at the seafloor, increasing bioturbation rates, and act as major links in local food chains. Compared to sites on the Farallon slope (1,010 - 3,085 m) and Pioneer Canyon (3,090 – 3,300 m), Monterey Canyon sites (2,300 - 3,300 m) had the highest mean abundance of ophiuroids.

Productivity Hotspots: Productive areas in rise habitats tend to be dynamic in space and time and, although they can last for decades, they are considered temporary and sometimes unpredictable.

- **Whale Falls** (Lundsten et al. 2010). Dead whale carcasses that sink to the deep seafloor introduce a massive pulse of energy capable of hosting dynamic communities of organisms in an otherwise food-limited environment. Carcass degradation at Monterey Canyon occurs sub-decadally.

- **Chemosynthetic Biological Communities** are productivity hotspots in slope, rise, and canyon habitats. See "Chemosynthetic Biological Communities" habitat summary for details. See Figure 6 for locations where CBCs have been observed in the Monterey Bay area.

HABITAT STRUCTURE

Species Composition**:** Invertebrates and fishes are the major animal groups on the rise. Few studies have been conducted at these deeper depths. The unique faunal assemblage found in Chemosynthetic Biological Communities is described in the CBC habitat summary.

- **Benthic Megafauna West of the Farallones** (Nybakken 1996, Nybakken et al. 1998). Benthic megafaunal invertebrates was sampled on the soft bottom slope (2,300-3,075 m) west of Farallones and in Pioneer Canyon (Monterey Canyon was not adequately sampled). The benthic invertebrate megafauna were dominated by echinoderms (mostly burrowers) with holothurians (cucumbers), ophiuroids (brittle stars), and asteroids (sea stars) in the upper three ranks. Distribution of megafaunal organisms is highly patchy, especially among surface-dwelling forms. Quantitative analysis of differences between sites and between survey years indicated that the megafauna associations at the same depth in MBNMS are really quite different at different sites. Results also suggest that there are strong seasonal and yearly differences within the same site.

- **Fishes on the California Rise** (Allen 2006; Neighbors and Wilson 2006). Common species of the rise are identified (Table 13).
- **Demersal Fishes West of the Farallones** (Cailliet et al. 1992, 1999). The deep-sea demersal fish fauna on the soft bottom slope and rise (2,000-3,300 m) west of Farallones appeared similar in species composition to the fauna of the eastern Pacific and other deep-water sites around the world. The fish fauna was dominated by families Macrouridae, Zoarcidae, Moridae, and Rajidae and included the following species: skate (*Bathyraja trachura*), spiny eel (*Notacanthus chemnitzii*), lizardfish (*Bathysaurus mollis*), snailfishes (*Paraliparis* spp., *Paraliparis rosaceus*, *Careproctus melanurus*, *Careproctus ovigerum*), cuskeel (*Spectrunculus grandis*), codling (*Antimora microlepis*), grenadier (*Coryphaenoides acrolepis*, *C. armatus*, *C. filifer*, *C. leptolepis*), eelpouts (*Lycenchelys* spp., *Pachycara lepinium*, *Bothrocara* spp.).
- **Benthic Fishes off Oregon, Washington, and Central North Pacific** (Pearcy et al. 1982). Families represented by the most species were Scorpaenidae, Liparidae, Zoarcidae on the slope (400-2,600 m) and Lipariddidae, Zoarcidae, Macrouridae on the abyssal plains (2,600-3,050 m). The bathymetric ranges of most species began or ended in three zones of rapid faunal change: 400-900 m, 1,900-2,200 m, 2,800-3,100 m. Species assemblages were characterized as follows:
    - Three species assemblages were recognized on the upper-slope (515-2,100 m, 800-2,500 m, 860-1,143 m; all dominated by thornyhead (*Sebastolobus* spp.);
    - One on the mid-slope (800-2,300 m; dominated by Pacific grenadier (*Coryphaenoides acrolepis*);
    - Two on the lower slope-abyssal plains (840-3,900 m, 2,100-5,180 m; dominated by abyssal grenadier (*Coryphaenoides armatus*).
- **Marine Mammals:** Even the deepest diving cetaceans (e.g., sperm whales and beaked whales) do not dive deep enough to forage on the benthic organisms in the rise habitat.

Species Composition Shifts: Long time-series data are lacking for most of the deep sea making it difficult to detect shifts in species composition and to understand the cause of those shift.

- **Natural Changes**: Significant natural changes in water temperature and current patterns, such as El Niño/La Niña events, can cause shifts in species composition of the benthic community. Food falls and periods of high productivity in surface waters deliver natural supplies of food to the seafloor, which in turn can rapidly change the species compositions at these depths.
    - **Whale Falls** (Smith and Baco 2003, Lundsten et al. 2010). Falls of large whales are a sporadic source of large-volume labile organic matter to the deep seafloor. Whale carcasses in the deep ocean off California may pass through three to four overlapping successional stages and this successional process may occur rapidly, in less than 10 years. The majority of species at Monterey Canyon whale fall communities are common deep-sea inhabitants of Monterey Canyon, nearby

seamounts, and the continental slope. See “Slope – Soft Bottom” habitat summary for additional information.

- **Major El Niño/La Niña Event** (Ruhl and Smith 2004). A major change in the community structure of the dominant epibenthic megafauna was observed at 4,100 meters (Station M) in the northeast Pacific and was synchronous to a major El Niño/La Niña event that occurred between 1997 and 1999. Photographic abundance estimates of epibenthic megafauna from 1989 to 2002 show that two taxa (cucumbers) decreased in abundance after 1998 by 2 to 3 orders of magnitude, whereas several other species (4 cucumbers, 1 urchin, brittlestar group) increased in abundance by 1 to 2 orders of magnitude. These faunal changes are correlated to climate fluctuations dominated by El Niño/La Niña. Correlations between food supply and megafauna abundance over the 14 year time period suggest that some taxa increase in abundance during periods of high food supply, whereas others may be favored during deficits.

- **Human-induced Changes**: Productivity, biomass, and physical energy are all relatively low in the deep sea, increasing the potential sensitivity to human impacts (Glover and Smith 2003). In addition, species diversity is relatively high in the deep sea, making the habitat more sensitive to human impacts.

  - **Carbon** D**ioxide Sequestration**. CO_2 injection at 3,600 m in Monterey Bay caused high rates of mortality in meiofauna (Barry et al. 2004). Hagfish (*Eptatretus stouti*) were more affected by respiratory stress associated with the high partial pressure of CO_2 than by the lowered pH (Tamburri et al. 2000). Liquid CO_2 introduced onto the seafloor at 3,250 m depth killed significantly greater numbers of representative infauna at the experimental site than at areas a distance away (Thistle et al. 2005). This demonstration that sequestered CO_2 can adversely affect the deep-sea infauna brings CO_2 sequestration in the deep sea into conflict with the preservation of deep-sea biodiversity. The principal impact to general benthic ecosystems is likely to be reduced pH, and for those organisms directly in the path of the CO_2 plume, physiological stress caused by an elevated partial pressure of CO_2 (Glover and Smith 2003).

Species Diversity and Species Richness: Species diversity in the deep sea is greater than once thought. Small patches (mm to m) of biogenic disturbance and food input (e.g., food falls), separated on spatial scales of meters to km, are important in maintaining high diversity in deep-sea communities. Low productivity, reduced broad-scale disturbance, and large surface area of the deep sea are relevant to maintenance of diversity. Because of the large surface area and the many undescribed species, diversity in the deep sea may rival that found in tropical rain forests (reviewed in Grassle 1989). High diversity makes this habitat sensitive to human impacts (reviewed in Glover and Smith 2003).

- **Whale Falls**. Local species diversity (mean of 185 macrofaunal species) on large whale skeletons during the sulphophilic stage is higher than in any other deep-sea hard substratum community (Smith and Baco 2003). Global species richness on whale falls (407 species) is also high compared with cold seeps and rivals that of hydrothermal vents (469 species worldwide). The majority of species at Monterey Canyon whale fall communities are common deep-sea inhabitants of Monterey Canyon, nearby seamounts, and the continental slope (Lundsten et al. 2010). Upon initial arrival, whale carcasses host a relatively low-diversity community of mobile scavengers. Through time, diversity increases; however, most of the increases in species richness come from background taxa that exploit abundant nutrients provided by the carcass.

Biomass**:** Productivity, biomass, and physical energy in deep sea (>1,000 m) are relatively low, increasing the potential sensitivity to human impacts (Glover and Smith 2003). Very little is known of the biomass in the soft-bottom rise habitat.

- **Invertebrates and Fishes** (Smith and Demopoulos 2003). The California slopes and basins harbor rich benthic assemblages:
  - Epibenthic megafauna (>2 cm) often are abundant (densities: 0.3-17 indiv/m^2). Echinoderms are particularly common with brittle stars and holothuroids dominating the megafauna, and at times attaining high biomasses (67+/- 30 g wet wt/m^2). Other taxa include gastropods, hexactinellid sponges, fishes (macrourids, zoarcids, hagfish), decapods and galatheids;
  - Macrobenthos (2 cm-300 µm) consist of a high diversity of taxa, especially polychaetes, agglutinating foraminifera, bivalves, cumaceans, tanaids, and enteropneusts, with biomass of 4-8 g wet wt/m^2 and abundances of 5,000-10,000 individuals/m^2;
  - Meiobenthos (300 µm-42 µm) are an abundant, but relatively poorly studied component of the slope benthos. Nematodes, calcareous and agglutinating foraminifera, and harpacticoid copepods abound in this size class, with forams and nematodes probably the most abundant. A small number of core samples (620-3,700 m) found foram biomass ranging from 2.6-1,700 g wet wt/m^2; foram biomass may approach and even substantially exceed that found in the macrofaunal and megafaunal size categories from similar depths;
  - Nanobenthos (<42 µm, including bacteria, Archaea, yeasts, ciliates, flagellates, and amoebae) constitute an important, but poorly evaluated component of the slope benthos. Limited studies suggest that California slope sediments harbor microbial biomasses high by the standards of the deep sea, and even shallow water.
- **Groundfish in Eastern North Pacific** (Pearcy et al. 1982). The benthic fish fauna was examined from beam and otter trawl surveys from the slope and abyssal plains off Oregon, Washington, and the central N. Pacific (400-5180m). Abundance and biomass was highest at the slope (North station: 515-805 m; 10.7/1000 m^2 and 2.9 g/m^2, respectively) and lowest on the Tufts Abyssal Plain (2,780-2,820 m; 0.6/1000m^2 and 0.2 g/m^2, respectively).

Key Species Interactions: Facilitation is one species interaction for which we have some information specific to the rise habitat. Much is yet to be learned in deep-water habitats.

- **Facilitation**
  - **Bioturbation** (Smith and Demopoulos 2003). Bioturbation, or the movement of sediment particles by animals, is a key ecosystem process in low-energy, depositional environments, such as much of the deep sea. Bioturbation results

from the sum of deposit-feeding, locomotion and home-building activities of benthos; rates of bioturbation thus provide an integrative measure of the physical activity of sediment assemblages (Pacific Ocean with reference to California slope).

- **Brittle Stars Impact Community Energetics** (Summers and Nybakken 2000). Because of their abundance, feeding behavior, and high activity levels, ophiuroids (brittle stars) are thought to significantly impact energetics and ecology of bathyal soft-bottom communities through utilizing, processing, and redistributing organic matter at the seafloor, increasing bioturbation rates, and acting as major links in local food chains. Compared to two other sites (Farallon slope 1,010-3,085 m and Pioneer Canyon 3,090-3,300 m), Monterey Canyon (2,300-3,300 m) had the highest mean abundance of ophiuroids.

Open Water

HABITAT OVERVIEW

All of the water in the 15,787 km^2 of Monterey Bay National Marine Sanctuary that is not associated with the seafloor is part of the open water habitat. The open water habitat has a total volume of approximately 18,670 km^3. This habitat is constantly moving and comprises a portion of the California Current system. The California Current is a southward flowing current that extends from shore to several hundred miles offshore and from the surface to depths of about 100 m. This current brings cooler, northern waters into the sanctuary. In deeper waters over the lower shelf and slope, the northward flowing California Undercurrent brings warmer southern waters into the sanctuary. In winter, this undercurrent often surfaces to become the northward flowing Davidson Current, inshore of the California Current. These currents vary in intensity and location, both seasonally and from year to year. MBNMS contains a mix of waters from these different currents.

The major currents are greatly influenced by a number of variables including the strength and direction of winds, ocean temperatures and salinity, the topography of the coastline, and the shape of the ocean bottom. Primarily during the spring and summer months, northwest winds drive nearshore surface waters up to 50 km offshore in a process called upwelling. The nearshore waters are replaced from below by colder, nutrient-rich waters. The surface waters off central California may be pushed even further offshore by numerous jets, filaments, and eddies. Some oceanographic features, such as upwelling shadows, do not move waters offshore, but instead retain waters in an area for a period of time. Many oceanographic features have somewhat predictable locations especially those tied to key features such as point and headlands. Features and processes that modify the flow of currents also influence dispersal of planktonic organisms and the spatial distribution of nektonic organisms.

Generally, the open water habitat can be divided into three depth zones: the epi-, meso-, and bathypelagic zones. The epipelagic zone includes the upper 200 m of the water column and has a total volume in MBNMS of 2,569 km^3. This zone receives high levels of light and is subjected to seasonal variations in temperature and salinity. The epipelagic zone supports a diverse and complex food web of plankton, invertebrates, fishes, turtles, seabirds, and mammals. The mesopelagic zone (200–1,000 m) and the bathypelagic zone (below 1,000 m) have total volumes of 7,250 and 8,854 km^3, respectively. The waters of these zones are characterized by low or no light, lower temperature and food availability, slower currents, and higher salinity and pressure. Organisms that live under these conditions require specialized adaptations for locating food and mates.

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	See page 80
Feeding Ground:	See page 81

Spawning/Breeding Ground:	See page 83
Migratory Corridor:	See page 84
Biogenic Habitat:	See page 84
Energy Flow:	
Primary Production:	See page 85
Benthic-Pelagic Coupling:	See page 86
Key Trophic Interactions:	See page 87
Key Trophic Cascades:	No specific information was found on this topic.
Productivity Hotspots:	See page 88
HABITAT STRUCTURE	
Species Composition:	See page 89
Species Composition Shifts:	See page 93
Species Diversity and Richness:	See page 97
Biomass:	See page 97
Key Species Interactions	No specific information was found on this topic.
MOVEMENT AND DISPERSAL	The movements of most open ocean fish appear to be correlated with movements of water masses, which can vary with season, current, and decadal weather pattern (Lowe and Bray 2006). Highly mobile species tend to search for environmental conditions most likely to contain prey patches. Young stages of larval fish tend to drift passively in the water column while older-stage larvae of some species (e.g., flatfishes and rockfish) exhibit diel vertical migration (Lowe and Bray 2006).
SPECIES OF SPECIAL INTEREST	See page 100

HABITAT SUMMARY

<u>HABITAT FUNCTION</u>

Functional Habitats

Nursery Habitat: Oceanographic features that concentrate planktonic organisms, such as retention zones and frontal zones, may serve as good nursery habitat for pelagic larval fish and invertebrates. By concentrating prey resources, including phytoplankton and small zooplankton, these features may support higher growth rates of larval fish and invertebrates than the surrounding waters.

- **Retention Zones** (reviewed in Morgan and Botsford 1998). Along the central California coast, plumes of upwelled water are usually found jetting to the southwest of promontories. These waters may then be retained in upwelling shadows or upwelling fronts. Localized retention zones hold and concentrate primary production and make it available for higher trophic levels. Planktonic consumers of this primary production, such as the pelagic larvae of fish and invertebrates, are also concentrated and retained in these zones. During upwelling relaxation events, water and entrained larvae can flow back toward shore leading to pulses of settlement in nearshore habitats (Wing et al. 2003).

- **Upwelling Shadow in Northern Monterey Bay** (Graham and Largier 1997). When upwelling occurs to the north of Monterey Bay, an upwelling shadow occurs in the northern portion of Monterey Bay. The water mass in the upwelling shadow exhibits cyclonic (counter-clockwise) circulation and strong thermal stratification with warm surface waters. Residence time is estimated to be 8 days. This feature should retain shelf-derived primary production so that it is available for higher trophic levels. The feature breaks down during prolonged (>7 days) relaxation events. Larvae with short planktonic stages (<10 days) released north of Monterey Bay during upwelling periods may be entrained in the northern part of the bay and remain available for settlement there. Positive buoyancy or upward movement of eggs and larval organisms will enhance their accumulation within the surface waters of the upwelling shadow.
- **Frontal Zones off Central California** (Bjorkstedt et al. 1997). Along the central California coast during the upwelling season, ichthyoplankton were abundant at upwelling fronts. Ichthyoplankton were distributed deeper offshore of the surface front. This pattern of distribution suggests that upwelling fronts may reduce cross-shelf transport of fish larvae (and increase retention of larvae near the front) by removing larvae from the surface Ekman layer.
- **Central California**. Larson et al. (1994) analyzed NMFS midwater trawl results to find recurrent patterns in the distribution of pelagic juvenile rockfish just prior to settlement. They found clear gradients in fish size. The smallest pelagic juveniles were often located offshore beyond the upwelling front while larger pelagic juveniles were found close to shore, even during active upwelling. This pattern is probably caused by passive offshore transport of smaller juveniles during upwelling and ontogenetic changes that allow larger fish to be less susceptible to offshore transport or actively engage in onshore transport. Pelagic juveniles of all sizes appeared to be advected closer to shore during relaxation events.
- **Frontal Zone off Point Reyes** (Wing et al. 1998, 2003). Cancrid crab larvae, particularly rock crabs (*Cancer antennarius, C. productus*) and Dungeness crab (*C. magister*), were found in the frontal waters off of Point Reyes between newly upwelled water and the relatively warmer water directly south of Point Reyes in the Gulf of the Farallones. Larvae in this group exhibit strong vertical migratory behavior, which resulted in local concentration in the cross-shelf front. Onshore movement of the larvae to juvenile habitat appeared to rely on upwelling relaxation events and alongshore flows. Seasonal rates of settlement to coastal habitats at Bodega Head were highest during wind relaxations.

Feeding Ground: Many species of marine mammals, seabirds, and predatory fish travel to MBNMS during part of the year to forage on locally abundant prey species, including jellies, krill, squid, anchovy, and sardine. Some of these predators do not reproduce in MBNMS, but forage here during the non-breeding season. Species that are observed in higher abundance in northern Monterey Bay (e.g., leatherback turtles, harbor porpoise, Sooty Shearwaters) may be attracted to a concentration of prey items associated with this retention zone.

- **Pelagic Fish** (Love 1996, Leet et al. 2001). A number of pelagic fish species travel to MBNMS to forage during the highly productive upwelling season. Examples include Pacific hake, Pacific bonito, basking shark, blue shark, albacore, and yellowfin tuna.
- **White Shark** (Pyle et al. 1996, Klimley et al. 2001, Kelly and Klimley 2003,Weng et al. 2007, Jorgensen et al. 2009). Tracking of white sharks using acoustic tags has revealed a regular presence/absence pattern in North American coastal habitats with presence peaking during the months of August through February followed by near-complete absence between mid-April and mid-July. The peak in shark abundance coincides with the peak occurrence of northern elephant seal pups (1-3 years of age), which are the preferred prey of adult white sharks. White sharks appear to have a preference for certain foraging hotspots including Año Nuevo Island, which is a primary elephant seal rookery in central California. In general, while near pinniped rookeries in autumn and winter, white sharks avoid the surface and use water to 50 m depth, consistent with a silhouette-based hunting strategy.
- **Leatherback Turtle** (Benson et al. 2007, 2011). A principal foraging area for leatherback sea turtles (*Dermochelys coriacea*) within the California Current includes the area between Point Sur and Point Arena extending offshore to the 200 m isobath (Figure 20). The preferred prey of leatherback sea turtles, brown sea nettles (*Chrysaora fuscescens*), are observed in high densities in the principle foraging area particularly within upwelling shadows and retention areas.
- **Seabirds** (Roberson 2002, NCCOS 2003, 2007). Many seabirds are not year-round residents in MBNMS, but forage in sanctuary waters during the non-breeding season. Species that breed at higher latitudes (e.g., Alaska) during the summer and have highest densities in the sanctuary from late-fall to early spring include: loons, grebes, Northern Fulmars, scoters, Herring Gulls, Glaucous-winged Gulls, Black-legged Kittiwakes, and Rhinoceros Auklets. Species that migrate to the sanctuary after breeding at lower latitudes (during the winter) or in the southern hemisphere and have highest abundance in MBNMS during the summer and fall include: Black-footed Albatross, Sooty Shearwaters, Leach’s Storm-Petrels, Buller’s Shearwaters, Brown Pelicans, and Xantus’s Murrelets.
- **Seabird Foraging Hotspots** (Research Planning Inc. 2006). Locations of concentrations, or ‘hotspots’, of seabirds were identified by USGS, NOAA, and MLML seabird, marine mammal, and sea turtle experts (Figure 21). Hotspots tend to be areas with elevated abundance of prey or located adjacent to nesting habitats during the breeding season.
    - **Storm-Petrel:** A seasonal (August-November) hotspot for Ashy and other Storm-Petrels was identified between the 200 and 1,000 m isobaths from Pescadero Point to Cypress Point.
    - **Cassin’s Auklet:** A seasonal (May-July) hotspots for Cassin’s Auklet was identified between the 200 and 1,000 m isobaths from Cypress Point to Pfeiffer Point.
    - **Sooty Shearwater:** Seasonal (June-September) hotspots for Sooty Shearwater were identified from the coast to 5 km offshore from Pleasure Point to Moss Landing

(northern Monterey Bay) and along the central California coast from Lopez Point to Mill Creek, and from Point Piedras Blancas to San Simeon.

  - **Marbled Murrelet:** A year-round hotspot for Marbled Murrelet was identified from the coast to 2 km offshore from Pillar Point to Moss Landing.
  - **Diving Birds, Gulls, and Seabirds:** Seasonal hotspots for diving birds (grebe, loons, cormorants), gulls, and/or seabirds (auks, storm-petrels, shearwaters, albatrosses) were identified for the waters around Devil's Slide Rock (February-August), Año Nuevo Island (February-August), Bird Rock (April-August), and Castle Rocks (February-August).

- **Blue Whale** (Croll et al. 2005). Blue whales are found in Monterey Bay during summer months when euphausiid densities are high. Whale foraging effort is concentrated on dense schools associated with the edge of the submarine canyon. The whales appear to concentrate their foraging activity on deeper layers of euphausiid schools (typically between 150 and 200 m) where adult euphausiids tend to be found.
- **Marine Mammal Foraging Hotspots** (Research Planning Inc. 2006). Locations of concentrations, or 'hotspots', of marine mammals were identified by USGS, NOAA, and MLML seabird, marine mammal, and sea turtle experts (Figure 22). Hotspots tend to be areas with elevated abundance of prey.
  - **Blue whale, humpback whale, Dall's porpoise, dolphin, and California sea lion:** Central Monterey Bay over the submarine canyon and from the Monterey Peninsula south to Partington Point from the coast out to the 1,000 m isobath was identified as a year-round hotspot for Dall's porpoise, dolphins, and California sea lions and a seasonal hotspot for humpback whales (March-November) and blue whales (March and November).
  - **Blue whale and humpback whale:** A seasonal hotspot for humpback whales (March-November) and blue whales (June-November) was identified between the 50 and 200 m isobaths from San Pedro Point to Point Año Nuevo.
  - **Harbor Porpoise**: Hotspots for harbor porpoise were identified over the shelf out to the 100 m isobath from Duxbury Point to Pescadero Point, Davenport to Moss Landing, and Purisima Point to Estero Point.

Spawning/Breeding Ground: Many species of seabirds, marine mammals, fish, and invertebrates (e.g., market squid, krill) are year-round residents in MBNMS and complete their life cycle in sanctuary waters. Some species (e.g., northern elephant seal) travel to MBNMS for the purpose of reproduction. A number of migratory fish species migrate to lower latitudes (e.g., the Southern California Bight and southern Baja California) to spawn. These species may avoid spawning off central California because of the vigorous upwelling in this region, which can advect spawned eggs and larvae far offshore (Allen and Cross 2006).

- **Seabirds** (Roberson 2002, NCCOS 2003, Research Planning Inc. 2006, NCCOS 2007). In general, the seabirds that nest along the coast or on offshore islands in MBNMS are resident species that are also present in the sanctuary during the non-breeding season (though relative abundance may vary by season). These species include: Ashy Storm-Petrel, Brandt's Cormorant, Pelagic Cormorant, Heermann's Gull, Western Gull, Caspian Tern, Forster's Tern, Common Murre, Cassin's Auklet, Pigeon Guillemot, Marbled

Murrelet, and Rhinoceros Auklet. The need to return frequently to the nest during the breeding season results in higher densities of these seabirds in the waters adjacent to nesting areas. For example:

- **Rhinoceros and Cassin's Auklets** in the waters surrounding Año Nuevo Island during the breeding season (spring and summer). This area includes the heads of Año Nuevo and Ascension Canyons;
- **Marbled Murrelet**s in the waters near Point Año Nuevo during the breeding season (April-July);
- **Common Murre**s in the waters around the Devil's Slide/Point San Pedro breeding colony;
- **Brandt's Cormorant** (April to August) in the waters around the breeding colonies at Devil's Slide/Point San Pedro, Año Nuevo Island, Bird Rock, and Point Lobos.

- **Marine Mammals** (NCCOS 2003, Research Planning Inc. 2006). In general, the marine mammals that reproduce in MBNMS are resident in sanctuary waters year-round (though relative abundance may vary by season). These species include: sea otter, harbor seal, northern elephant seal, harbor porpoise, Dall's porpoise, and bottlenose dolphin. Steller sea lion density is elevated near the rookery at Año Nuevo Island, especially during the breeding season (May-July). The density of northern elephant seals is elevated throughout much of the year near the breeding and molting beaches at Año Nuevo Island, Piedras Blancas and Cape San Martin/Gorda.

Migratory Corridor:

- **Gray Whale** (Rice and Wolman 1971, NCCOS 2003). The coastal waters over the continental shelf in MBNMS are part of a migratory corridor for gray whales. Gray whales are seen migrating southward through MBNMS between mid-December and mid-February with abundance typically peaking in January. Some pregnant females give birth in MBNMS waters during the southward migration (Karin Forney, per. comm.). The northward return migration primarily occurs between February and May with abundance typically peaking in March. Gray whales tend to be observed in shallow coastal waters often within 1-3 nautical miles (1.8-5.6 km) of shore except in Monterey Bay where they may travel across the mouth of the bay through very deep water (Figure 22).

Biogenic Habitat: Habitat created by plants or animals is generally lacking in the open water environment. However, there are a few examples of smaller organisms living in close association with larger organisms or drifting kelp mats, which likely provide benefits such as food, shelter from predation, or improved dispersal.

- **Marine Snow** (Silver et al. 1998, Mary Silver, pers. comm.). Many different types of micro-organisms and small zooplankton (e.g., copepods) live on or in association with sinking particles of marine snow and with larger zooplankton-derived aggregates, such as abandoned larvacean mucous houses.
- **Floating Kelp Mats** (Cascorbi 1999c, Allen and Cross 2006). Ocean-going mats of kelp provide shelter to many species that otherwise find little shelter in the open ocean, including juvenile sea turtles, swimming crabs, and the young of important sport and commercial fishes such as jacks, sablefish, rockfishes, and yellowtail.

- **Gelatinous Organisms:** Medusafish (*Icichthys lockingtoni*), bluefin driftfish (*Psenes pellucidus*), and smalleye squaretail (*Tetragonurus cuvieri*) associate with medusa, siphonophores, and salps (Allen and Cross 2006). Graham (1994) found that megalops and juveniles of the slender crab (*Cancer gracilis*) commonly cling to large scyphomedusae (*Chrysaora fuscescens*) in central California waters. This association may help to enhance growth, survival, cross-shelf transport and dispersal of the crabs.

Energy Flow

Primary Production: Phytoplankton are the only source of primary production in the open water habitat. Sufficient sunlight to support photosynthesis only penetrates the waters of the epipelagic zone. Primary production shows high temporal and spatial variability in sanctuary waters. This variability is driven by many factors including:

- **Iron Availability** (Hutchins et al. 1998, Firme et al. 2003). Varying degrees of iron-limitation are found in the coastal upwelling region of central California during the summer. Iron-limitation is most common and severe in regions removed from continental shelf sources of iron. Thus, areas with a wide continental shelf (e.g., Monterey Bay and the shelf to the north) tend to have waters that are iron-replete compared to areas with a narrow shelf (south of Monterey Bay). Iron-limitation tends to be more severe during upwelling relaxation events because the phytoplankton community rapidly depletes the amount of dissolved iron in an upwelled water mass as it ages during the relaxation event. In iron-replete waters, ample iron allows for unrestricted growth of large phytoplankton (primary productivity is limited instead by the amount of nutrients, light, and grazing) and results in high production of particulate organic nitrogen and carbon. In contrast, in iron-limited waters, the growth rate of phytoplankton is low. Small phytoplankton and bacterioplankton dominate the plankton community leading to reduced production of particulate organic nitrogen and carbon.
- **Upwelling** (Chavez 1996, Pilskaln et al. 1996). Upwelled waters - the deep, cool, nutrient-rich waters that replace nearshore surface waters - support rapid growth of phytoplankton populations. For example, primary production in Monterey Bay exhibits a strong seasonal pattern, with lower rates of approximately 500 mg C/m^2/day from October to February (non-upwelling season), and higher, more variable rates on the order of 1,500 mg C/m^2/day during the upwelling season of March-July/August. There is considerable interannual variation in the timing and intensity of upwelling.
- **El Niño Event**s (Chavez 1996, Pilskaln et al. 1996, Chavez et al. 2002). Phytoplankton production usually decreases during El Niño events. During the 1992-93 El Niño, total phytoplankton abundance and primary production rates measured in March 1992 were reduced by factors of three to four compared to March 1990. March 1992 primary productivity levels were on the order of only 500 mg C/m^2/day whereas productivity values exceeded 1,000 mg C/m^2/day in both March 1990 and 1991. The reduction in coastal California primary productivity associated with the strong 1997–1998 El Niño was estimated to be 50 million metric tons of carbon (5×10^{13} g C). Chlorophyll was reduced on average to less than 50% of normal and was down to 20% of normal during the late 1998 upwelling season. This reduction certainly had deleterious effects on zooplankton and higher trophic levels.

Benthic-Pelagic Coupling: There is a two-way exchange, or flux of matter, between the benthos and the overlying water body, which is important for both benthic and pelagic compartments. This flux occurs through the sinking of non-living organic matter and the active movement of organisms.

- **Sources of downward flux:**
  - **Particulate Organic Carbon** (Pilskaln et al. 1996). Flux rates of small particle flux to the deep-sea are coupled to surface productivity. POC flux to midwater sediment traps deployed at 450 m varied from a minimum of 10 mg $C/m^2/d$ in December to 120 mg $C/m^2/d$ in May. The mean annual POC flux at 450 m was estimated to be 14.4 g $C/m^2/yr$ for Monterey Bay.
  - **Larvacean Houses**: The abandoned mucous houses of the giant larvacean *Bathychordaeus* are a significant source of rapid carbon transport through the water column and to the deep seafloor. Flux calculations in Monterey Bay, based on an average abundance of approximately 1 house per 100 ml, indicate that abandoned houses may seasonally account for 15% of overall carbon flux at 500 m (Silver et al. 1998). More recently, Robison et al. (2005) estimated the production rate of 1 sinking *Bathychordaeus* house per day in Monterey Bay to be approximately 5.4 mg of total organic carbon. This number is an underestimate of total flux of giant larvacean houses because there are at least two other species found in Monterey Bay.
  - **Whale Falls** (Smith and Baco 2003, Lundsten et al. 2010). Falls of large whales are a sporadic source of large-volume labile organic matter to the deep seafloor.
  - **Settlement of pelagic larvae or juveniles:** Flux to the benthos of live organisms occurs during settlement of pelagic larval and juvenile stages. The majority of benthic invertebrates and fish release pelagic eggs or larvae.
  - **Deposition of benthic eggs:** Some pelagic species (e.g., market squid, grunion) deposit eggs on the seafloor. (See "Shelf I & II - Soft Bottom" habitat summary for an estimate of the density of benthic eggs laid by market squid in southern Monterey Bay).
- **Sources of Upward Flux:**
  - Macrophytes, including large kelps, smaller algae, and seagrasses, are major primary producers in the marine environment, but only grow in relatively shallow nearshore habitats. Periodically large storms and other disturbances cause parts of the macrophytes to break loose and these floating rafts are a source of food and shelter in offshore surface waters.
  - Many marine organisms (including infaunal and epifaunal invertebrates and demersal fish) release eggs and/or larvae that are pelagic.
  - Benthic Feeding by Pelagic Organisms: Many pelagic species consume benthic organisms living in the soft and hard bottom habitats of the shelf, slope and rise. For example, northern elephant seals and sperm whales dive hundreds of meters to capture demersal fish. In addition, during ROV surveys of deep-sea habitats in Monterey Bay, pelagic organisms, such as medusae and isopods, have been observed

grabbing detritus on the seafloor and taking it up into the water column (Bruce Robison, pers. comm.).

- **Diel Vertical Migration**: Nocturnal diel vertical migration is a behavior in which organisms residing at deeper depths during the day rise to the surface or near-surface waters at night. This behavior enables organisms to feed in the relatively productive surface waters at night while avoiding visual predators during the day. Vertical migration occurs in almost all of dominant taxa in the Monterey Bay zooplankton community, including copepods, krill, crab larvae, cladocerans, polychaetes, chaetognaths, siphonophores, ctenophores, larvaceans, and bryozoan larvae (Carr et al. 2008). The families Myctophidae (lanternfishes), Gonostomatidae (bristlemouths), Stomiidae (dragonfishes), and Gempylidae (snake mackerels) are representative of the types of fish species that undergo diel vertical migration (Allen and Cross 2006).

Key Trophic Interactions: Phytoplankton is the primary source of primary production in the oceans and forms the base of the open water food web. Zooplankton and small, schooling fishes comprise the principal linkage between phytoplankton and higher trophic levels. Sinking particulate organic matter (POM) and larger detritus is a primary source of food for pelagic organisms in deeper waters.

- **Planktivores in the Epipelagic Zone:** Planktivory is the base of the pelagic food web in the epipelagic zone. Zooplankton (e.g., copepods, krill, jellies, and larval fish and invertebrates) and filter feeding fish (e.g., anchovy, sardine, herring) are some of the major consumers of phytoplankton.
- **Suspension Feeders in the Mesopelagic Zone**: Gelatinous zooplankton, including pteropods, salps, and appendicularians, are suspension feeders that capture sinking POM using mucous sheets, nets, strands, and filters. These organisms play a significant role in processing and transporting nutrients throughout the oceans.
- **Predation on Schooling Zooplankton and Small Fishes**
    - Examples of predators of euphausiids (krill):
        - Marine Mammals: blue whale, humpback whale, fin whale, minke whale, gray whale.
        - Seabirds: Sooty Shearwaters, Common Murres, Rhinoceros Auklet, Cassin's Auklet, Ashy Storm-Petrel, Leach's Storm-Petrel, Fork-tailed Storm-Petrel, Western Gull, Sabine's Gull, Red Phalaropes.
        - Fish: salmon, juvenile rockfish, Pacific butterfish, speckled and Pacific sanddabs, Pacific hake, anchovy, blue sharks, Pacific herring, juvenile rockfishes.
        - Invertebrates: Humboldt squid, brown sea nettles.
    - Examples of predators of market squid:
        - Marine Mammals: California sea lion, Steller sea lion, harbor seal, northern elephant seal, northern fur seal, Dall's porpoise, harbor porpoise, Pacific white-sided dolphin, bottlenose dolphin, Risso’s dolphin, short-beaked common dolphin, northern right whale dolphin, short-finned pilot whale, killer whale, bottlenose whale, beaked whales, sperm whale, humpback whale, fin whale.

        - Seabirds: Black-footed Albatross, Laysan's Albatross, Sooty Shearwater, Pink-footed Shearwater, Short-tailed Shearwater, Northern Fulmar, Ashy Storm-Petrel, Black Storm-Petrel, Fork-tailed Storm-Petrel. Pelagic Cormorant, Brandt's Cormorant, Common Murre, Pigeon Guillemot, Rhinoceros Auklet, Marbled Murrelet, California Gull, Mew Gull, Glaucous-winged Gull, Heermann's Gull, Black-legged Kittiwake.
        - Fish: croakers, plainfin midshipman, curlfin turbot, Pacific sanddab, lingcod, petrale sole, California halibut, Pacific bonito, salmon, yellowtail, California barracuda, blue shark, common thresher shark, albacore, and blue, bocaccio, chilipepper, copper, cowcod, greenblotched, greenstriped, olive, and vermillion rockfish.
    - Examples of predators of anchovy and sardines:
        - Marine Mammals: California sea lion, Steller sea lion, harbor seal, northern elephant seal, northern fur seal, Dall's porpoise, harbor porpoise, Pacific white-sided dolphin, bottlenose dolphin, short-beaked common dolphin, northern right whale dolphin, humpback whale, minke whale.
        - Seabirds: Western and Clark's Grebes, Brown Pelican, Brandt's Cormorant, Pelagic Cormorant, Arctic Loon, Sooty Shearwater, Pink-footed Shearwater, Short-tailed Shearwater, Buller's Shearwater, Western Gull, California Gull, Mew Gull, Glaucous-winged Gull, Heermann's Gull, Bonaparte's Gull, Black-legged Kittiwake, Pomarine Jaeger, Common Murre, Rhinoceros Auklet, Pigeon Guillemot, Marbled Murrelet, Xantus's Murrelet, Craveri's Murrelet, Tufted Puffin.
        - Fish: common thresher shark, blue shark, marlin, yellowtail, albacore, barracuda, bonito, mackerel, hake, salmon, California halibut, jacksmelt, topsmelt, plainfin midshipman, and bocaccio, canary, chilipepper and vermillion rockfish.
        - Invertebrates: Humboldt squid, large jellies (e.g., sea nettle *Chrysaora fuscescens)*

Productivity Hotspots: The process of upwelling brings iron-replete, nutrient-rich waters into the photic zone over the continental shelf. Areas with high rates of upwelling, or where upwelled waters are retained, tend to be hotspots of primary productivity.

- **Upwelling Centers** (Broenkow 1996). Two coastal upwelling centers are present in MBNMS: one near Point Año Nuevo and a stronger one south of Point Sur.
- **Upwelling Zones** (TNC 2006). Recurring patterns of cold surface water were used to identify upwelling zones in northern and central California (Figure 23). Average sea surface temperature (based on AVHRR data compiled by NOAA Coast Watch) during the upwelling season (March - September) was determined for the years 2000-2003. In general, most of the upwelling zones were defined as having May-June temperatures between 9-12 ºC. The strongest upwelling centers in central California were identified at Point Reyes, Davenport, Big Sur and Point Conception; these are areas where upwelling is persistent and strong and probably enhanced by coastal headlands. Upwelling of cold nutrient-rich waters occurs in early spring and summer and generally peaks in May and June; however, there is significant variability in upwelling between years and with latitude.

- **Persistent Fronts** (CoastWatch 2007, unpubl. data). The CoastWatch Oceanic Front Probability Index (FPI) measures the probability of sea surface temperature front formation based on data from NOAA's GOES satellites (Nearshore areas are not surveyed by the GOES data). Daily average SST is generated from the GOES data. Fronts are identified by applying an edge detection algorithm to this daily averaged SST field (Breaker et al. 2005). Pixels with gradients greater than 0.375 °C are classified as a front. The frontal probability index is then calculated as the number of times a pixel is classified as a front divided by the number of cloud-free days per month. Pixels with a monthly FPI of 20% or greater are selected and averaged for all months within a given season, for the entire duration of the data set (2001-2006). Figure 24 shows the FPI in MBNMS by season
- **Frontal Zones** (Ryan et al. 2005). A transitory frontal zone was identified in northern Monterey Bay over the sloping inner shelf in waters ~20- 50 m deep. High concentrations of phytoplankton were measured in association with this front.
- **Iron-replete Waters** (Firme et al. 2003). Iron-replete waters support higher primary productivity. In MBNMS, iron-replete waters tend to be found over the continental shelf and near upwelling centers. Iron-replete waters occur further from shore in areas with a wide continental shelf, such as Monterey Bay and along the coast to the north of Monterey Bay, than in areas with a narrow continental shelf, such as the Big Sur coast south of Monterey Bay.

HABITAT STRUCTURE

Species Composition: Phytoplankton and zooplankton are very abundant in the surface waters of the open water habitat. Crustaceans (copepods, krill, larvae of macro-crustaceans) and larvae of pelagic fish constitute a large portion of the zooplankton. The composition of the larval fish assemblage varies throughout the year since the timing of spawning and larval duration varies for different species, and from year to year with environmental fluctuations. A small number of coastal pelagic species, including market squid, northern anchovy, Pacific sardine, Pacific hake, and jack mackerel, provide important linkages in the marine food web, supporting a wide variety of higher-level predators, including other fishes, seabirds, and marine mammals. Gelatinous zooplankton are abundant in both the epi- and mesopelagic zones. Seabirds, marine mammals, and leatherback turtles are important predators in the epipelagic waters of MBNMS. Only a few species of deep-diving mammals are important predators in the mesopelagic zone.

- **Phytoplankton** (summarized in Sliver et al. 1996). Netplankton (>20 microns) are responsible for seasonal blooms during the upwelling season. The phytoplankton smaller than 20 microns (the 2-20 micron nanoplankton and the <2 micron picoplankton) can contribute the largest proportion of the phytoplankton biomass and production during non-upwelling periods.
- **Epipelagic Zooplankton** (Silver et al. 1996). Dominant groups are crustacean larvae, copepods, euphausiids (krill), ctenophores (comb jellies), hydrozoan medusae, siphonophores, and chaetognaths (arrow worms).
  - **Copepods**: Epipelagic zooplankton is often dominated by copepods, including *Acartia, Paracalanus, Calanus pacificus, Metridia pacifica, Pleuromamma,* and

Oithona. Copepods appear to be separated to some extent into niches that are onshore-offshore, depth and migration related.

  - **Euphausiids**: Net samples collected in Monterey Bay revealed that euphausiid schools are highly variable in species and size structure (Croll et al. 2005). On average a school consisted of 68.32 (±34.75)% *Euphausia pacifica*, 30.17 (±34.95)% *Thysanoessa spinifera*, and 1.51 (± 2.56)% other species.
  - **Gelatinous Organisms**: The epipelagic zone contains numerous small hydrozoan medusae and larger scyphozoan medusae (e.g., purple striped jelly *Chrysaora colorata*, sea nettle *Chrysaora fuscescens*, moon jelly *Aurelia* spp., and egg yolk jelly *Phacellophora camtschatica*), siphonophores (e.g., *Muggiaea*), comb jellies (e.g., *Pleurobrachia*, *Leucothea*), by-the-wind-sailor (*Velella velella*), larvaceans (e.g., *Oikopleura longicauda*), salps, doliolids, and pteropods (e.g., *Corolla*, *Clione*).

- **Meso- and Bathypelagic Zooplankton** (Silver et al. 1996). Below the epipelagic zone, the zooplankton fauna is much less well known. Recently, observations from ROVs and submersibles have allowed study of this group. The invertebrate fauna is dominated by eight phyla:
  - Ctenophora (comb jellies): a number of species including *Kiyohime usagi;*
  - Cnidaria: hydrozoans (e.g., *Solmissu*s), the red/purple medusa (*Atolla*), the black medusa (*Vampyrocrossota childressi*), and siphonophores (*Apolemia* spp., *Praya dubia*, *Nanomia* spp.);
  - Nemertea (ribbon worms): pelagic worms including *Nectonemertes* spp.;
  - Annelida (segmented worms): mesopelagic worms including *Tomopterus*, *Alciopina, Poebius* and *Vanadus;*
  - Chaetognatha (arrow worms): at least 15 species in three families, including *Caecosagitta macrocephala, Flaccisagitta hexaptera, Parasagitta euneritica, Pseudosagitta lyra, Pseudosagitta maxima*, and *Solidosagitta zetesios;*
  - Arthropoda (mainly Crustacea): ostracods (e.g., *Conchoecia* spp., *Gigantocypris*), copepods (e.g., the black copepod, *Gaussia princeps,* and numerous types of red copepods), mysid shrimp (e.g., *Gnathophausia ingens, Boreomysis* spp., *Eucopia* spp.), amphipods (over a dozen species including the genera *Hyperia, Paraphronima, Vibilia, Paracallisoma, Phronima, Scina, Orchomenella, Primno, Cystisoma, Streetsia, Cyphocaris*, and many species in the family Gammaridea), krill (*Euphausia pacifica, Nematoscelis difficilis, Thysanoessa spinifera*), adult shrimp (*Sergestes similis, Pasiphaea pacifica, P. emarginata, P. chacei, Parapasiphaea sulcatifrons, Gennadas propinquus*), and the larvae of galatheid crabs;
  - Mollusca: The nektonic mollusks include at least 23 species in 14 families. The most common cephalopods in the water column are *Doryteuthis* (*=Loligo) opalescens, Histioteuthis heteropsis*, *Gonatus* spp., and *Chiroteuthis calyx*;
  - Chordata: larvaceans including the "giant larvaceans" *Bathochordaeus*.

- **Epipelagic and Mesopelagic Organisms** (Bruce Robison, pers. comm.). The upper 1,000 m of the water column over the Monterey Canyon has been studied by Bruce

Robison's lab at MBARI since 1992. Table 14 provides a preliminary evaluation of the relative frequency of sightings of the most commonly observed organisms in 100 m depth strata based on data collected between 2000-2002.

- **Ichthyoplankton in Central California** (Bjorkstedt et al. 1997, 2002). Ichthyoplankton were sampled at night from two depth layers (0-27 and 27-55 m depth) at 3 km intervals at upwelling fronts along the central California coast during the upwelling season of 1993 and 1994. Common taxa captured included rockfishes, lanternfishes (*Stenobrachius leucopsarus, Diaphus theta, and Tarletonbeania crenularis*), deep-sea smelts (*Bathylagus* spp. and *Leuroglossus* spp.), sanddabs, and Pacific sardines.
- **Ichthyoplankton in Central California** (Lenarz et al. 1991). The abundance and distribution of late larvae and pelagic juvenile fishes were surveyed at three depths (13, 37, and 117 m) along the central California coast. The following species were captured: rockfish (bocaccio, darkblotched, bank, black, shortbelly, squarespot, canary, stripetail, chilipepper, halfbanded, yellowtail, brown, widow, blue, pygmy), Dover sole, rex sole, northern anchovy, Pacific hake, speckled sanddab, and Pacific sanddab.
- **Ichthyoplankton Assemblages Along the U.S. West Coast** (Doyle et al. 2002). The ichthyoplankton assemblages prevailing along the U.S. West Coast during spring are mainly structured according to water depth and reflect the distribution and habitat preference of the adults. They include a coastal/shelf assemblage, a slope assemblage, and an oceanic assemblage (Table 15). The slope assemblage represents a transition between the shelf and oceanic assemblages, containing some species from both.
- **Epipelagic Nekton** (Silver et al. 1996; see Table 16 for a more extensive list of species found in central California). The nektonic (strong swimmers) assemblage in the upper 200 m of the water column of MBNMS is characterized by:
    - **Cephalopods**: The most important squid species along the California coast is the market squid (*Doryteuthis opalescens*). Two large relatively common squid are the boreal clubhook squid (*Onychoteuthis borealijaponicus)* and the robust clubhook squid (*Moroteuthis robustus)*. Historically, the Humboldt squid (*Dosidicus gigas*) had been an occasional visitor to central California, but it has been observed in Monterey Bay year-round since 2002 (Zeidberg and Robison 2007);
    - **Cartilaginous Fish:** Common species include blue shark, common thresher shark, shortfin mako shark, basking shark, and spiny dogfish. Less common species include the bigeye thresher shark, salmon shark, soupfin shark, white shark and pelagic stingray;
    - **Bony Fish**: The epipelagic bony fishes are very diverse and commonly include anadromous fishes (e.g., Chinook salmon), anchovies, sardines, Pacific saury, tunas (e.g., albacore, Pacific bonito), jacks and jack mackerels (e.g., Pacific mackerel, jack mackerel), swordfish, Pacific hake, Pacific butterfish, yellowtail, North Pacific frostfish, opah, louvar, ocean sunfish, and medusafish. Rarer pelagic species include the prowfish, oilfish, oxeye oreo, and lancetfish.
- **Mesopelagic and Bathypelagic Nekton** (Silver et al. 1996; see Table 16 for a more extensive list of species found in central California). The meso- and bathypelagic fishes are quite diverse, including lanternfishes (Myctophidae), bristlemouths

(Gonostomatidae), hatchetfishes (Sternoptychidae), slickheads (Alepocephalidae), deepsea smelts (Bathylagidae), spookfishes and barreleyes (Opisthoproctidae), barbeled dragonfishes (Stomiidae), snailfishes (Liparidae), eelpouts (Zoarcidae), bigscales (Melamphaidae), fangtooths (Anoplogastrodae), dreamers (Oneirodidae), and ribbonfishes (Trachipteridae) as well as pelagic juvenile flatfishes and rockfishes.

- **General Classification of California Marine Fishes:** Allen and Pondella (2006) used cluster analysis to identify fish species assemblages in different habitats (by depth and latitude). The following species assemblages occur in open water habitats of central California:
    - Open Ocean Pelagics (rarely over continental shelf): sharks (soupfin, white, salmon, common thresher, blue, shortfin mako, bigeye thresher, smooth hammerhead), ocean sunfish, tunas (albacore, bluefin, bigeye, skipjack, yellowfin), opah, swordfish, striped marlin, dolphinfish;
    - Migratory Coastal Pelagics (migrate northward in summer and southward in winter): Pacific bonito, yellowtail;
    - California Coastal Pelagics (common over continental shelf): northern anchovy, Pacific sardine, Pacific pompano;
    - Southern Coastal Pelagics (more abundant off southern California, but also found off central California): Pacific and jack mackerel, California barracuda and white seabass.
- **Epipelagic Assemblages in Central and Northern California**: NCCOS (2003) used data collected from NMFS midwater trawl surveys to identify seven assemblages of pelagic fish and invertebrate species that tended to be collected together off northern and central California (Table 11). Assemblages differed to some extent by depth, but all occur in epipelagic waters.
- **Midwater Fish Species Composition in Central and Northern California** (Sullivan 1995). Cluster analysis was used to group northern and central California Commercial Passenger Fishing Vessel (CPFV) fishing locations based on similarities in species composition. Most of the fishes included in the analyses were rockfishes (RF); other species included lingcod, Pacific hake, sablefish, Pacific sanddab, and petrale sole. Fishing locations ranged from Pescadero Point to Point Sur. The data set was separated into two species groups: midwater schooling species, and benthic species. For the midwater schooling species, six location groups were geographically and bathymetrically distinct:
    - **Canyon Ledge** (edge of Monterey Canyon and edge of Carmel Canyon): chilipepper with Pacific hake;
    - **North Shelf** (shelf near shelf edge starting west of Monterey Canyon and extending northwest along coastline to Davenport): chilipepper with yellowtail and bocaccio RF;
    - **South Depth Transition** (mid-depth areas between Monterey and Point Sur): chilipepper with yellowtail, blue and widow RF;
    - **Monterey Flats** (mid-depth locations, south side of Monterey Bay, with few mid-depth nearshore locations adjacent to North Shelf area): widow, yellowtail, bocaccio RF;

- **South Shallow** (all shallow locations from Monterey to Point Lobos): blue and yellowtail RF;
- **North Shallow** (shallow locations from Davenport north to Pescadero Point); blue and black RF, with yellowtail RF.

- **Seabirds and Mammals** (Harvey 1996, Research Planning Inc. 2006). The spatial and temporal patterns of seabird and marine mammal abundance in MBNMS determine species composition at any given location (Table 12). Many of the species that occur in MBNMS are highly transitory; some species migrate through MBNMS while others move into the sanctuary seasonally to feed on locally abundant prey. Some species are most common in the sanctuary during the breeding season and others tend to be resident year-round. The movements of many species appear to be associated with patterns in prey abundance and oceanographic conditions.
- **Marine Mammals** (Keiper et al. 2005). In a study of marine mammal occurrence patterns along the central California coast (Bodega Bay to Monterey Bay) during spring and summer from 1986-1994 and 1997-1999, 23 species were observed; 54% of all sightings were pinnipeds (seals and sea lions), 36% odontocetes (toothed whales, dolphins and porpoise), 9% mysticetes (baleen whales) and 1% sea otters.
    - Species sighted most frequently: California sea lion, northern fur seal, Pacific white-sided dolphin, Dall's porpoise, harbor porpoise, and humpback whale.
    - Species sighted infrequently or seasonally: gray whale, minke whale, sei whale, short-beaked and long-beaked common dolphins, Risso's dolphin, northern right whale dolphin, killer whale, Cuvier's beaked whale, Steller sea lion, and northern elephant seal.

Species Composition Shifts:

- **Natural Changes:** Changes in the physical and chemical properties of surface waters, such as iron availability and temperature, may have substantial impacts on the abundance of phytoplankton as well as the species composition of the phytoplankton community. Reductions in phytoplankton biomass may lead to changes in the abundance of organisms at higher trophic levels. These changes may occur over short time periods, such as relaxation events during the upwelling season, or they may persist for years (e.g., El Niño events) or even decades (e.g., PDO).
    - **Harmful Algal Blooms** (Scholin et al. 2000). In May 1998, a harmful algal bloom was observed in Monterey Bay. During the HAB event, the dominant diatom species switched from primarily *Chaetoceros* spp. to *Pseudo-nitzschia australis*. *P. australis* produces domoic acid, a neurotoxin, which was found in high levels in anchovy, sardines and California sea lions in central California.
    - **Iron Availability** (Hutchins et al. 1998, Firme et al. 2003). Iron in surface waters tends to be more available during upwelling and more limited during upwelling relaxation events. Iron-replete and iron-limited waters tend to differ in the associated phytoplankton communities and relative biomass at many trophic levels:

    - **Characteristics of Iron-replete Waters:** Ample iron allows for unrestricted growth of large diatoms and dinoflagellates. The community growth rate is high and supports increased biomass at upper trophic levels.
    - **Characteristics of Iron-limited Waters**: Pico and nanoplankton dominate the plankton community. Large diatoms and dinoflagellates are rare. Biomass at upper trophic levels is reduced.
- **Upwelling** (Silver et al. 1996). Species composition of plankton (>20 microns) changes under different oceanographic conditions. During the upwelling season (generally spring and summer), colony-forming diatoms, particularly species of *Chaetoceros, Rhizosolenia, Skeletonema,* and *Pseudo-nitzschia* are dominant. In the fall and occasionally during interludes in the upwelling season, dinoflagellates tend to dominate (especially during warming intervals). Aggregations of dinoflagellates, such as *Prorocentrum, Ceratium*, and *Gonyaulax,* sometimes produce red tides during this period.
- **El Niño Events**: El Niño events off central California affect the composition and structure of biological communities. Some of the changes appear to be related to reduced upwelling-associated primary production and a subsequent reduction in zooplankton and forage fish biomass. In addition, changes in current patterns and increased water temperature are related to an increase in the abundance of warm-water associated pelagic species and a decrease of cold-water associated pelagic species off central California.
    - **Phytoplankton in Monterey Bay** (Silver et al.1996). During the 1982-83 El Niño event (the strongest in a century) dramatic changes in the phytoplankton composition of Monterey Bay were documented, including increased relative abundance of dinoflagellates and tropical species, decreased abundance of diatoms, and a significant increase in species diversity of plankton (>20 microns).
    - **Zooplankton in Monterey Bay** (Marinovic et al. 2002). Zooplankton abundance and euphausiid community composition were sampled seasonally (spring, summer, fall) within Monterey Bay, California, between 1997 and 1999. During the 1997-98 El Niño, both total zooplankton and krill abundance dramatically declined coincident with a rapid increase in SST and mixed layer depth. The composition of the euphausiid community also changed; the relative abundance of the southern species *Nyctiphanes simplex* increased while the abundance of cold temperate *Euphausia pacifica* and northern *Thysanoessa spinifera* declined. Zooplankton abundance, euphausiid community composition, and physical oceanographic parameters gradually returned to a more typical upwelling-dominated state in the spring and summer of 1998. By the spring and summer of 1999, both zooplankton and euphausiid abundance had increased to the highest levels recorded during the 3-year study. Both *E. pacifica* and *T. spinifera* abundance increased while *N. simplex* was absent. These changes reflected the cooler, highly productive environmental conditions associated with the 1998/1999 La Niña.
    - **Humboldt Squid in Monterey Bay** (Zeidberg and Robison 2007). Humboldt squid recently expanded its perennial range into Monterey Bay. Based on monthly

ROV surveys of the water column (0-1,000 m) in Monterey Canyon, this species was not observed in Monterey Bay from 1989 to 1997. Humboldt squid first appeared during the onset of the strong 1997–1998 El Niño and persisted through most of 1998. In 2002 Humboldt squid returned in abundance, associated with a small El Niño event, and have been present in Monterey Bay year-round ever since. The numbers of Pacific hake, a prey items of Humboldt squid, have been significantly lower during periods when the squid was present and the seasonal pattern of hake abundance also has been altered. The authors found that the sustained range expansion of Humboldt squid coincided with changes in climate-linked oceanographic conditions and a reduction in competing top predators (such as billfish and tuna).

- **Migratory Fish**: Species of migratory fish with a distribution centered south of Point Conception (e.g., young thresher sharks, louvar, skipjack tuna, striped marlin, Pacific mackerel, and jack mackerel) may increase in relative abundance off of central California during warm water events (Leet et al. 2001, Starr et al. 2002a). Southern species with elevated abundance in MBNMS during El Niño events include kelp bass, Pacific barracuda, and bluefin tuna.
- **Seabirds** (Roberson 2002). Species that migrate to MBNMS primarily during warm-water events include: Black-Vented Shearwater, Least Storm-Petrel, boobies, tropicbirds, frigatebirds, and Craveri's Murrelet.
- **Cetaceans in Monterey Bay** (Benson et al. 2002). The assemblage of odontocetes (toothed cetaceans) in Monterey Bay became more diverse during the 1997-98 El Niño, with a temporary influx of warm-water species (e.g., common dolphins) and decreased abundance of cold-water species (e.g., Dall's porpoise). A dramatic reduction in zooplankton (e.g., krill) biomass offshore during the El Niño appears to have concentrated baleen whales (e.g., humpback whales, blue whales) in the remaining productive coastal upwelling areas, including Monterey Bay.

- **Pacific Decadal Oscillation (PDO)**: The PDO is a long-term pattern of North Pacific climate variability with phases that persist from 20-30 years. The positive (warm) phase of the PDO is characterized by cooler than average sea surface temperatures and air pressure near the Aleutian Islands and warmer than average sea surface temperatures near the California coast. The negative (cool) phase tends to reverse these climatic patterns. A full cycle of the PDO - a warm phase and a cool phase - appears to take approximately 50 years. Instrumental data provide evidence for two full cycles: cool phases from about 1900 to 1925 and 1950 to 1975 and warm phases from about 1925 to 1950 and 1975 to the mid-1990s (Chavez et al. 2003).
  - **Salmon** (PFEL Climate Variability and Marine Fisheries 2005). Salmon stocks off California, Oregon, and Washington increase during the cool phase and decrease during the warm phase of the PDO. Salmon stocks in Alaska show the opposite pattern. This "reciprocal oscillation" has been observed over the 70 years of available records.
  - **Sardine vs. Anchovy** (Chavez et al. 2003). Off central California, landings of anchovies and sardines appear to vary with the PDO. Anchovy abundance is

highest during cool phases and sardine abundance is highest during warm phases of the PDO. In the mid-1970s, the Pacific changed from a cool "anchovy regime" to a warm "sardine regime". A shift back to an “anchovy regime” appears to have occurred in the middle to late 1990s.

- **Human-Induced Changes:** A variety of human activities have alter species composition in the open water habitat. Whaling, seal and otter hunting, and collection of seabirds and their eggs led to the drastic reduction of some marine mammals and seabird populations in the 1800s and 1900s; many of these populations are still recovering (Tables 6 and 7). Though seabirds and marine mammals are protected from directed take, oil spills, ship strikes, and bycatch in fisheries can result in significant mortality events. Strong fishing pressure on some pelagic species, such as sardines, basking sharks and large tunas, has contributed to reduced abundance of some fish populatins in the open water habitat (Table 4).
    - **Bycatch of Sensitive Species in Gillnets** (Forney et al. 2001). During the 1980s and 1990s, there appeared to be extensive bycatch of seabirds and marine mammals in central California's set gillnet fishery. Species observed entangled in gillnets during 1990-1994 include two Double-crested Cormorants (*Phalacrocorax auritus*), one Pacific Loon (*Gavia pacifica*), six unidentified alcids, three unidentified cormorants, 101 California sea lions (*Zalophus californianus*), 44 harbor seals (*Phoca vitulina*), and 18 northern elephant seals (*Mirounga angustirostris*). Historical entanglement rates for three sensitive species (sea otters, harbor porpoise, and Common Murres) were combined with estimated fishing effort in 1995-1998 to create mortality estimates of 5,918-13,060 Common Murres (S.E. 477-1,252), 144-662 harbor porpoises (S.E. 18-53), and 17-125 sea otters (S.E. 4-25). In 2002 the California Department of Fish and Game implemented a prohibition on the use of set gillnets in waters shallower than 60 fathoms (approximately 110 meters) in central California to reduced the risk of entanglement of seabirds and marine mammals, including sea otters, harbor porpoise, and Common Murres.
    - **Oiling of Sensitive Species** (Luckenbach Trustee Council 2006). In 2001, extensive tarball deposits along the coastline of MBNMS were estimated to have killed thousands of seabirds, including grebes, cormorants and Common Murres. The source of these tarballs remained unknown for several months, but was ultimately tracked to the SS *Jacob Luckenbach* which sank off San Francisco in 1953 (currently located in the Gulf of the Farallones National Marine Sanctuary). Subsequent investigative work matching the oil samples indicated this vessel was the likely source of a number of tarball and oiled bird incidents dating back to at least 1992. During the period of spills linked to the SS *Jacob Luckenbach*, over 51,000 birds and eight sea otters were estimated to have been killed from north of Bodega to Point Lobos. The remaining oil and fuel were removed from this sunken ship removing threat of further spills.
    - **Long-term Changes in Trophic Level of Marbled Murrelet:** Becker and Beissinger (2006) compared the stable isotope composition of feathers from Marbled Murrelets living along the central California coast in the last decade with those collected over 100 years ago. Nitrogen isotope ratios indicated that during the pre-breeding season murrelets were foraging on prey one-half a trophic level lower than they were 100 years ago. Carbon isotope ratios suggest that this trophic shift is caused

by murrelets now eating less anchovy, sardine, and squid (high-trophic level), and more juvenile rockfish (mid-trophic level) and krill (low-trophic level). The authors suggest that high-trophic level prey (anchovy, sardine and squid) are now less available to Marbled Murrelets because of human extraction of these prey species.

Species Diversity and Species Richness: The central California coast is an area where the ranges of subtropical species and temperate species overlap. The transitional nature of the area contributes to both the high species richness and the diversity observed at all trophic levels. Processes, such as El Niño, that alter the location and physical features of water masses have measurable influences on species diversity in the sanctuary (see “Species Composition Shifts – Natural Changes” section above for more details).

- **Deep-sea Fishes** (Neighbors and Wilson 2006). Species diversity of the deep sea fish fauna in the eastern and central Pacific tends to increase with distance offshore. The nutrient-rich waters closer to shore support fewer, but more abundant species than offshore waters, which support a higher diversity of species that are less abundant.
- **Seabirds** (NCCOS 2003, 2007). Areas in MBNMS with the highest species diversity of seabirds were Pioneer Canyon, Año Nuevo/Ascension/Cabrillo Canyon, inner Monterey Bay, inner Monterey Canyon, Carmel Canyon and the slope off Point Sur. The seabird fauna is the least diverse during the upwelling season (March – August) and the most diverse during the Davidson Current season (November – March).
- **Marine Mammals.**. The marine mammal fauna is the most diverse in the fall because this is a time when summer migrants (e.g., blue, humpback and minke whales) are still present and winter migrants (e.g., many species of dolphin) begin to arrive (Harvey 1996).

Biomass: Generally, zooplankton biomass in the California Current is highest in the upwelling season (late spring-early fall). This high biomass at lower trophic levels supports seasonally elevated biomass at higher trophic levels, such as pelagic predatory fishes, seabirds, and marine mammals. Both phytoplankton and zooplankton production varies with physical factors, including oceanographic conditions, temperature, currents, and eddies.

- **Zooplankton** (summarized in Silver et al. 1996). In MBNMS, zooplankton are usually more abundant in waters over the continental shelf compared to waters in the offshore California Current. Zooplankton abundance generally declines from the epipelagic to the mesopelagic and bathypelagic zones. A strong seasonal pattern is evident in zooplankton biomass, with the highest amounts observed in spring and summer. Spawning of pelagic larvae by shallow benthic invertebrates may be timed to coincide with phytoplankton blooms. Some circulation features can concentrate zooplankton biomass. In a study of epipelagic zooplankton biomass at three stations offshore of Monterey Bay, the annual mean zooplankton biomass ranged from 216.7 to 726.4 mg/m^2 (Little 2003).
- **Jellies** (Graham et al. 2010). Acoustic-sampling techniques, in combination with net sampling, was used to estimate the abundance and distribution of scyphozoan jellies (*Aurelia* spp., *Chrysaora colorata*, *Chrysaora fuscescens*, and *Phacellophora camtschatica*) off central California. Echo-integration methods applied to regions where

net catches contained jellyfish resulted in an estimate of a mean density of 251,522 jellies per square nautical mile and a mean concentration of 0.003 jellies/m^3.

- **Euphausiids** (Croll et al. 2005). Topographic breaks in the continental shelf located down-current from upwelling centers work in concert with the diel vertical migratory behavior of euphausiids to collect and maintain large concentrations of euphausiids. For example, dense schools of euphausiids aggregate between 80 and 180 m on the offshore edge of the Monterey Canyon. High euphausiid densities are supported by high primary production between April and August and a submarine canyon that provides deep water down-current from an upwelling region. Mean euphausiid densities in Monterey Bay are 1.3 g/m^3 (39 individuals per m^3). Peak euphausiid densities occur in late summer/early fall, lagging the seasonal increase in primary production by 3 to 4 mo.
- **Harvested Species:** Harvest removes biomass of targeted fish and invertebrate populations. For some targeted species, biomass is substantially reduced compared to unfished biomass levels (Tables 3 and 4). However, the size of some of these populations, such as anchovy and sardine, is affected strongly by environmental conditions (e.g., El Niño events, PDO).
- **Deep-sea Fishes** (Neighbors and Wilson 2006). Biomass of the deep-sea fish fauna in the eastern and central Pacific tends to decrease with distance offshore. The nutrient-rich, cooler coastal waters support higher abundance and biomass than the warmer waters of the central Pacific.
- **Leatherback Turtles Population Estimate** (Benson et al. 2007). Aerial surveys over waters <92 m in depth off central and northern California during 1990−2003 were used to determine foraging population estimates for leatherback turtles. The greatest proportion of turtles was encountered within the two central California strata (Monterey Bay and Gulf of the Farallones), accounting for an average of 72% of the total abundance. For all years combined, estimated leatherback turtle abundance averaged 140 within the central California strata and 178 for the entire study area. Average density estimates were 3.6 and 1.3 turtles/km^2 for the Gulf of the Farallones and the Monterey Bay strata, respectively.
- **Leatherback Turtle Hotspots** (Benson et al. 2007, 2011). Hotspots, areas where leatherback sea turtles have been encountered most frequently, were identified in central California by the offshore Environmental Sensitivity Analysis (RPI 2006) and updated based on personal communication with Scott Benson (March 2012). In summer and fall leatherbacks are most frequently encountered over the shelf in northern Monterey Bay, between Pigeon Point and Pillar Point, and between Half Moon Bay and San Francisco (Figure 20). These hotspots are part of the principle foraging area - Area 1 identified in Title 50 Code of Federal Regulations, Part 226.207 (77 Federal Register 4170). Brown sea nettles (*Chrysaora fuscescens*), the preferred prey of leatherback sea turtles, are observed in high densities in the principle foraging area, particularly within upwelling shadows and retention areas. Critical habitat for leatherback sea turtles also includes offshore waters utilized by leatherbacks when gelatinous prey availability in the principal foraging area is poor (Figure 20).
- **Seabirds** (NCCOS 2003, 2007). Sooty Shearwaters and Common Murres dominate seabird biomass along the central California coast. In MBNMS, high seabird biomass

densities occur off Half Moon Bay, just south of Point Año Nuevo, and in inner Monterey Bay. Biomass densities are especially high over the continental shelf and slope.

- **Seabirds** (Research Planning Inc. 2006). Areas of high seabird biomass often are close to breeding colonies, along migration routes, or in areas where prey tends to be seasonally abundant. Figure 21 shows the location of hotspots for some species of seabirds. Additional information is available in 'Feeding Ground' and 'Spawning/Breeding Ground' sections above.
- **Seabird Hotspots in the California Current** (Nur et al. 2011). Data from at-sea surveys of seabirds over an 11-year period (1997-2008) were combined with information on habitat features (bathymetry and oceanography) to predict hotspots for seabirds in the California Current Ecosystem. Single species model predictions for 16 species were combined to identify potential hotspots of multispecies seabird aggregation using three criteria: overall abundance among species, importance of specific areas to individual species, and predicted persistence of hotspots across years (Figure 25). Areas of high overall abundance and high species importance were associated with the Farallon Islands and Monterey Bay. There was substantial overlap between areas identified as highly persistent and those identified as having high summed abundance and/or high species importance. No hotspots were apparent more than 90 km offshore. Bathymetric variables were found to be important predictive variables of seabird hotspots, whereas oceanographic variables derived from remotely sensed data were generally less important.
- **Marine Mammals** (NCCOS 2003, Research Planning Inc. 2006). Areas of high biomass of marine mammals often are close to breeding colonies (e.g., pinnipeds), along migration routes (e.g., gray whales), or where prey tends to be seasonally abundant. Figure 22 shows the location of hotspots for some species of marine mammals. Additional information is available in 'Feeding Ground' and 'Spawning/Breeding Ground' sections above.
- **Blue Whales** (Croll et al. 2005). Blue whale sightings from whale watching trips between 1992 and 1996 indicate that blue whales were seasonally present in Monterey Bay between June and November. Blue whale density during the time period of peak abundance (August) was 0.034 whales km^2. Blue whales were concentrated along the edge of the Monterey Canyon.
- **Cetaceans in the California Current Ecosystem** (Barlow et al. 2009, Forney et al. 2012, Becker et al. in review, Karin Forney, pers. comm.). Data from 15 large-scale shipboard cetacean and ecosystem assessment surveys conducted in the temperate and tropical eastern Pacific during the period from 1986 to 2008 were combined with environmental predictors (e.g., bathymetry, salinity, sea surface temperature) to model finer scale cetacean densities within the California Current Ecosystem. The models were developed and validated for individuals species or species groups. Modeled densities for 7 toothed whales and 3 baleen whales are shown in Figure 26. The highest predicted densities occurred in MBNMS for blue whales and humpback whales, to the west of MBNMS for offshore species (e.g., fin whales, sperm whales, beaked whales, striped dolphins), to the north of MBNMS for northern species (Dall's porpoise, northern right

whale dolphin, Pacific white-sided dolphin), and to the south for warm-temperate species (short-beaked common dolphin).

- **Harbor Porpoise** (Carretta et al. 2009)**.** Two sets of aerial survey transects, one inshore (out to the 90 m isobath) and one offshore (between the 90 and 200 m isobath), conducted between 2002-2007 were used to estimate density and abundance of harbor porpoise between the CA/OR border and Pt. Conception. In MBNMS, harbor porpoise density was highest in the inshore area and lowest in the offshore area south of Pt. Sur (Figure 27).

SPECIES OF SPECIAL INTEREST

Many species of special resource management interest occur in the open water habitat of MBNMS Tables 3-7. Most of these species are wide-ranging and not affiliated closely with benthic habitats.

- ***Species Landed in MBNMS*****:** Of the 10 invertebrate and 156 fish species that are commonly caught and sold in the commercial and/or recreational fisheries of MBNMS (Starr et al. 2002a), one invertebrate (market squid) and 55 fishes occur in the open water habitat.
- ***Endangered and Threatened Species:*** There are no known endangered or threatened invertebrate species in the open water habitat. Three threatened and two endangered fish taxa occur in open water during a portion of their life, but they also rely on coastal habitats that are negatively impacted by human activities. The leatherback turtle is the only endangered reptile to occur regularly in the open waters of the sanctuary. All of the 3 listed seabirds and 10 listed marine mammals occur in open water.
- ***Other At-Risk Species:*** None of invertebrate taxa in the federal waters of MBNMS are considered to be at-risk. Five at-risk fishes occur in open water. The leatherback turtle, along with all 11 at-risk birds and 9 at-risk mammals, occur in open water.

Additional species of special resource management interest in the open water habitat include:

- Krill due to their important ecological role as a primary food source for seabirds, marine mammals and fishes;
- Sooty Shearwaters which reach extremely high densities during the summer, when hundreds of thousands of adults forage for fishes and squid in sanctuary waters after migrating from the southern hemisphere;
- Seabirds (e.g., Common Murres, Rhinoceros Auklets, Brandt’s Cormorants, loons, grebes) and marine mammals (e.g., harbor seals, harbor porpoise, elephant seals, sea otters) vulnerable to disturbance, injury or death from human activities in the sanctuary such as oil spills and entanglement in fishing gear.

Submarine Canyon

HABITAT OVERVIEW

Submarine canyons are prominent geomorphic features within Monterey Bay National Marine Sanctuary (Figure 2). Submarine canyons, much like onshore river valleys, are erosional features that carve into the seafloor and expose older, underlying strata in canyon walls. Submarine canyons have sinuous channel axes, sometimes with a number of branching channels. Monterey Canyon, in the center of Monterey Bay, is the largest of these submarine features – both in the sanctuary and along the entire coast of North America. Similar in size to the Grand Canyon in Arizona, it is 470 km long and approximately 12 km wide at its widest point, with a maximum rim to floor relief of 1,700 meters. Numerous smaller canyons cut into the continental shelf and slope of the sanctuary. The walls and floors of submarine canyons constitute approximately 16.3% of the area of the sanctuary (Table 2). Within the federal study area, the vast majority of canyon habitat in is soft-bottom (1,993 km^2) and a much smaller portion is hard-bottom (126 km^2).

The heads of submarine canyons tend to be found near the continental shelf edge. In areas with a very narrow continental shelf, the canyon heads are located near the shoreline and appear to act as major conduits for the transport of sediments to the deep sea. The heads of Monterey Canyon, Carmel Canyon, and Partington Canyon reach very close to shore and are probably the most active conduits of materials to deep-water habitats in the sanctuary. Submarine landslides on steep canyon walls also deposit sediments on the canyon floor. Organic material associated with sediments, including nutrients and pollutants, are delivered to the canyon floor by sediment transport events. These processes may also lead to an accumulation of marine debris on the canyon floor, or move it out on the Monterey Fan. Sediment transport events are thought to be episodic. Potential triggering events include storms, earthquakes, moderate sea and surf conditions, and flooding rivers.

Most organisms observed in canyons are not unique to canyon systems but are also found at similar depths outsides canyons. Because submarine canyons extend from shallow waters to the deep sea, they contain an incredible diversity of organisms. Mobile fishes and invertebrates, such as prickly sharks and krill, have been found to aggregate in canyon heads and along canyon walls. Rocky outcrops along canyon walls are colonized by invertebrates - including sponges, feather stars, corals and tunicates - and provide shelter for a variety of fishes. Clams and worms burrow into canyon walls. Soft sediments on the canyon walls and floor support a diverse community of invertebrates (e.g., sea pens, sea cucumbers, brittle stars, sea stars) and fishes (e.g., flatfishes, ratfishes, whiptails, grenadiers, sablefish, hake, thornyheads).

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	See page 102

Feeding Ground:	See page 103
Spawning Ground:	See page 103
Migratory Corridor:	See page 104
Biogenic Habitat:	See page 104
Energy Flow:	
Primary Production:	No specific information was found on this topic in this habitat category. See "Slope – Hard Bottom" habitat section for general information on this topic.
Benthic-Pelagic Coupling:	See page 106
Key Trophic Interactions:	Detritivores, animals that feed on organic matter found in or on bottom sediments, dominate benthic communities in the deep sea. Most of the detritus that arrives in deep-sea habitats, originated in coastal habitat and surface waters where sunlight fuels photosynthesis.
Key Trophic Cascades:	No specific Information found during literature review
Productivity Hotspots:	No specific Information found during literature review
HABITAT STRUCTURE	
Species Composition:	See page 107
Species Composition Shifts:	See page 110
Species Diversity and Richness:	See page 111
Biomass:	See page 111
Key Species Interactions	No specific information was found on this topic.
MOVEMENT AND DISPERSAL	See page 112
SPECIES OF SPECIAL INTEREST	See page 113

HABITAT SUMMARY

<u>HABITAT FUNCTION</u>

Functional Habitats

Nursery Habitat: The shallow waters of submarine canyon heads appear to be used as nursery habitats by some species of fish and invertebrates. Over time, individuals move down the canyon into deeper habitats as they grow larger and mature.

- **Spot Prawn** (Schlining and Spratt 2000). A comparison of the size distribution of male spot prawn (*Pandalus platyceros*) collected at multiple sites along the edge of Carmel Canyon (between 200-400 m) showed that the canyon head might be acting as a refuge for smaller males. The authors suspect that juveniles may use even shallower habitats of the canyon head, 100-200 m, as a nursery habitat.

- **Pacific Hake** (Vetter and Dayton 1999). Juvenile Pacific hake (*Merluccius productus*) were so abundant between 150 and 200 m in Scripps Canyon (in southern California), that at times their bodies obscured visibility. Large numbers of juvenile hake have been observed in Carlsbad and Redondo Canyons.

Feeding Ground: Consumers in canyons potentially experience enhanced food supply, compared to those at similar depths outside canyons, through several mechanisms: suspension feeders may benefit from accelerated currents; demersal planktivores may exploit dense layers of krill and zooplankton that become concentrated in canyons during downward vertical migrations; and food for detritivores may be increased by high sedimentation rates in canyons or through accumulation of macroalgal detritus (Vetter and Dayton 1998, 1999).

- **Pacific Hake** (Vetter and Dayton 1999). Juvenile Pacific hake were very abundant in Scripps, Carlsbad, and Redondo Canyons in southern California. High abundance in canyons may be due, in part, to higher food availability in the canyons.
- **Macroalgal Detritus** (Vetter and Dayton 1999). In the axis of La Jolla and Scripps Canyon, megafaunal abundance was positively associated with macroalgal detritus. This increased abundance appeared to be due to utilization of detritus as food by some species (e.g., sea cucumbers and sea urchins) and as food and shelter by other species (e.g., crabs and amphipods).
- **Benthic Siphonophores** (Vetter and Dayton 1999). The greater abundance of the benthic siphonophore *Dromalia alexandri* in La Jolla and Scripps Canyons, relative to adjacent shelf and slope habitats, may be due to enhanced current flows in canyon habitats that increase flux of food particles past this filter feeder. This species is common in submarine canyon habitats of MBNMS.
- **Large Animals Falls** (Smith and Baco 2003, Goffredi et al. 2004, Lundsten et al. 2010). Recent time-series studies of natural and implanted deep-sea whale falls off California indicate that these carcasses initially attract mobile scavengers, such as sleeper sharks, hagfish, rattails and crabs, that can remove soft tissue at high rates (40-60 kg/day). Degrading carcasses also serve as a food source for numerous species of benthic invertebrates including polychaete worms, echinoderms (brittle stars, sea cucumbers, sea urchins), sipunculids, and nemerteans. Over a 10-year period of exploration of ~180 km^2 of seafloor in Monterey Bay, the remains of eight marine mammals (three whales, two seals, one elephant seal, and two of unknown identity) have been discovered. Six of the eight remains were found in the axes of submarine canyons, suggesting that deposition of large animal remains is relatively common in submarine canyon habitats and an important source of organic matter to these habitats. Carcass degradation occurs sub-decadally.

Spawning Ground: Fish that typically inhabit the deeper waters of the rise and slope may move up the axes of submarine canyons into the shallower waters of the canyon head to spawn. The restricted area of the canyon heads may concentrate spawning fish into dense aggregations.

- **Elasmobranchs**: Possible mating aggregations of filetail catsharks (*Parmaturus xaniurus*) and longnose skates (*Raja rhina*) were observed during ROV surveys of the headward part of Ascension Canyon (Bizzarro et al. 2003). Prickly sharks (*Echinorhinus* *cookeri*) aggregate frequently over the head of the Monterey Canyon and it is possible that they are aggregating to mate (Starr et al. 1999).

- **Pacific Hake**: Spawning populations of Pacific hake (*Merluccius productus*) are found at depths of 130-500 m (Airamé et al. 2003).

Migratory Corridor: The axis of a submarine canyon may serve as a migratory corridor for mobile species. Some species may move up or down the canyon for seasonal migrations (e.g., feeding or breeding migrations). Some species may progressively move down the canyon as they grow older and larger (i.e., ontogenetic migration).

- Many species of flatfish have juveniles that settle in shallower habitats and slowly move into deeper waters as they mature. Many flatfish species may use progressively deeper soft-bottom habitats of submarine canyons during this process of ontogenic migration.
- Prickly sharks (*Echinorhinus cookei*), sevengill sharks (*Notorynchus maculutus*), and lysianassid amphipods are among several deep-water species that migrate up the Monterey Canyon into the shallow head (Varoujean 1972, Okey 2003).

Biogenic Habitat: Many species of structure-forming invertebrates are found along the walls of submarine canyons. Though structure-forming invertebrates are more common on hard substrates, some species (e.g., sea pens) are found in soft sediments. Some demersal fishes and mobile invertebrates (e.g., crabs and shrimp) are found in association with structure-forming invertebrates. Two other biogenic habitats common in canyons - chemosynthetic biological communities (CBCs) and macrophyte (large plant) detritus - are important sources of both food and shelter for demersal fish and invertebrates. CBCs are most common along canyon walls whereas macrophyte detritus accumulates along the canyon floor. Detailed information about these two biogenic habitats can be found in the "Chemosynthetic Biological Communities" and "Macrophyte Detritus" habitat sections.

- **Structure-forming Invertebrates** are an important component of fish habitat. Most rockfish observed in Soquel Canyon were associated with some habitat structure, including crinoids, sea anemones, and sponges (Yoklavich et al. 2000). Monterey Bay Aquarium Research Institute (MBARI) scientists have used ROVs to survey canyon habitats in the Monterey Bay region since 1989. Structure-forming species, including stony corals, black corals, hydrocorals, crinoids, sponges, and sea pens are frequently observed in submarine canyon habitat (Figures 8 and 13).
- **Structure-forming Invertebrates in Ascension and Carmel Canyon** (Bianchi 2011). The manned submersible *Delta* was used to survey megafaunal invertebrates and demersal fishes during 12 dives in Ascension Canyon (182-319 m) and 12 dives in Carmel Canyon (90-305 m). Structure-forming invertebrates were classified as megafaunal invertebrates with complex morphology and/or large size (>20 cm in height). Fish associations with structure-forming invertebrates were recorded.
    - **Ascension Canyon:** A total of 3,155 structure-forming invertebrates were observed during 12 submersible dives. The following types of structure-forming species were observed (listed in order of decreasing abundance): mound sponge, foliose sponge, white-plumed anemone, swimming anemone, white deep-sea corals, shelf sponges, barrel sponges, upright sponges, sand anemones, Subselliflorae sea pens, vase sponges, basket stars, branching sponges,

gorgonians, plumed sea pens, and octocorals. Sebastes/*Sebastomus* fishes (e.g., darkblotched, splitnose, and rosethorn rockfish) were observed: inside vase sponges (n=66); under swimming anemones (n=321), foliose sponges (n=405), and upright sponges (n=100); and at rest next to Gorgonian corals (n=15), branching sponges (n=19) and vase sponges (9%).

    - **Carmel Canyon:** A total of 6,369 structure-forming invertebrates were observed during 12 submersible dives in Carmel Canyon. The following types of structure-forming species were observed (listed in order of decreasing abundance): foliose sponge, mound sponge, Subselliflorae sea pens, upright sponges, barrel sponges, white deep-sea corals, octocorals, gorgonians, swimming anemone, shelf sponges, vase sponges, branching sponges, white-plumed anemone, plumed sea pens, basket stars, and pom pom anemones. Sebastes/Sebastomus fishes (e.g., pygmy rockfish, half-banded rockfish, darkblotched rockfish, and greenstriped rockfish) were observed: under vase sponges (n=107), barrel sponges (n=507), and upright sponges (n=534); and at rest next to basket stars (n=16) and vase sponges (5%). We also observed Dover and/or English sole underneath plumed sea pens (n=23]) and next to Subselliflorae sea pens (n=676).

- **Structure-forming Invertebrates Observed in MBNMS Shelf Characterization Surveys** (IfAME and MBNMS 2011). Video transects using a remotely operated vehicle (ROV) and a towed camera sled were made to characterize the distribution of fishes, invertebrates, and seafloor habitats between 50 and 400 m at five locations in MBNMS: Ascension and Año Nuevo Canyons; North Monterey Bay; Carmel Bay and Point Lobos; Point Sur Shelf; and La Cruz Canyon and Point Piedras Blancas. Transects covered a varied of canyon habitat including canyon rim, canyon head, and canyon floor. Structure-forming invertebrates were commonly observed in canyons. Specific locations where structure-forming invertebrates were observed along the transects are available through the Shelf Characterization and Image Display website (http://sep.csumb.edu/ifame/scid).

- **Deep-sea Corals** (Etnoyer and Morgan 2003, 2005). Records on 8 habitat forming deep-sea coral families from 10 different institutions were gathered to create a dataset of range and distribution of corals along the west coast of North America. Monterey Canyon was identified as an area of highest occurrence of deep-sea corals. Examples of species associated with corals include: crabs and fishes (resting/refuge), fish egg cases (attachment substrate in well-aerated water column), and crinoids, basket stars, and anemones (suspension feeding).

- **Deep-sea Coral Habitat Suitability** (Guinotte and Davies 2012). The potential distribution of deep-sea corals was modeled for the U.S. West Coast Exclusive Economic Zone. Predicted habitat suitability in MBNMS is shown separately for 6 deep-sea coral taxa (Figure 10). Some of the highest habitat suitability probabilities for each taxa occurred in portions of submarine canyon habitat (such as canyon walls and canyon heads). However, the model will likely overpredict the amount of suitable habitat in some areas (e.g., indicate suitable coral habitat in areas that are known soft bottom regions) because fine-scale bathymetric features (10's of meters), substrate, and current data were not available for the entire study area.

Energy Flow

Benthic-Pelagic Coupling (reviewed by Raffaellia et al. 2003). There is a two-way exchange, or flux of matter, between the benthos and the overlying water body, which is important for both benthic and pelagic compartments. This flux occurs through the sinking of non-living organic matter (e.g., falling plankton, fecal pellets, animal carcasses, and drift algae) and the active movement of organisms. Areas of high productivity and areas where surface and mid-water planktonic species are concentrated tend to have higher rates of flux of organic matter to the seafloor. Additional background information located in Appendix III.

- **Sources of Downward Flux:**
  - **Marine Snow** (review by Rex 1981). Most deep benthic communities are supplied with food by a "rain of detritus" including dead organisms, discarded feeding structures, fecal pellets, and other organic debris. Most of the particles that reach the deep seafloor are less than 5 mm in size, sink slowly, and have organic carbon levels that are reduced by microbial mineralization during their descent, which may last for months. Carbon flux associated with sinking particulate organic matter was estimated to range from 9-182 mg C/m^2/day in the axis of Monterey Canyon (from subsurface sediment traps located at 450 m; Pilskaln et al. 1996). In general, open ocean locations with high primary productivity, such as upwelling plumes and retention zones, will be areas with high delivery of particulate organic carbon (POC) to the seafloor in the form of sinking organisms.
  - **Sinking Larvacean Houses** (Robison et al. 2005). Larvaceans, a type of small mid-water animal, feed by filtering seawater through a mucus net called a ‘house’. When the filtering apparatus in the house becomes clogged, the larvacean casts off the old house and forms a new one. Abandoned houses sink to the seafloor at rate of ~800 m/day and they are observed along the floor of the Monterey Canyon at densities as high as 1/m^2. Over 10 years, the average flux of houses to the seafloor was 3.9/m^2/day. Per house, the average total organic carbon was 5.4 mg and the average C:N ratio was 6.09. The rate of nutrient flux was calculated to be 7.6 g C/m^2/year and this number is probably an underestimate. Sinking houses are not detected by conventional sampling methods (sediment traps) so they have never before been included in calculations of vertical nutrient flux. Recent models of carbon flux through the deep water column predict that only ~10% of the POC that sinks below 100 m reaches depths beyond 1000 m. These results reveal a pathway through this region that carries substantially more carbon than has been measured by conventional methods. This study found that discarded mucus feeding structures carry a substantial portion of the upper ocean's productivity to the deep seafloor.
  - **Macrophyte Detritus** (Harrold et al. 1998, Vetter and Dayton 1998, 1999, Okey 2003). The higher biomass and density of soft bottom macrofauna in canyons (compared to sites at similar depth on the shelf and slope) are likely supported by nutrient enrichment from macrophyte detritus. Studies in Monterey Canyon and Carmel Canyon in central California and La Jolla and Scripps Canyon in southern California have found that drifting plant material (algae and surfgrass) accumulates in the heads of the canyons and is delivered periodically down the canyon mouth by sediment flows. A comparison of the daily flux of organic carbon derived from

macroalgal detritus in Carmel Canyon to estimates of carbon flux from vertically sinking POC in the nearby Monterey Canyon revealed that drift algae accounted for 20-83% of the total POC reaching the seafloor in Carmel Canyon.

- **Horizontal Delivery of Carbon Down the Axis of Submarine Canyons** (Jim Barry, pers. comm.). Jim Barry and colleagues are using sediment traps to measure carbon flux down the Monterey Canyon and at one non-canyon site (at ~1300 m). The traps are collecting material that moves horizontally down the canyon, not just vertically from the surface and mid-water. They have found that the head of the canyon has frequent sediment movement events and that these events deliver carbon to the mid-canyon site. The mid-canyon site has approximately 20 times more sediment flux to it than the outer canyon and non-canyon sites.
- **Large Animal Falls** (Rex 1981). Megafauna in the deep sea are often opportunists that scavenge animal carcasses on the seafloor. On February 6, 2002, a well-preserved carcass of a gray whale was discovered at 2,891 m depth in the axis of Monterey Canyon (Goffredi et al. 2004). This carcass delivered approximately 20,000 kg of organic material to the seafloor.

HABITAT STRUCTURE

Species Composition: Similar to patterns observed in benthic habitats on the continental shelf, slope and rise, demersal fish and invertebrates in submarine canyons tend to be distributed according to depth and bottom type. The distribution of seabirds and marine mammals tends to be influenced strongly by both distance from shore and water depth. The presence of submarine canyons, especially those with canyon heads that are close to shore, can allow deep-water species to be found in much closer proximity to shallow water species than is observed in areas without canyon habitats. The detailed information below refers only to observations made in submarine canyons.

- **Infaunal Invertebrates Along the Monterey Canyon Ridge** (Oliver and Slattery 1976). Sediment movement and depth were the most important environmental parameters affecting the distribution of macro-invertebrates in the head of the Monterey Canyon. All sampling stations were located in waters less than 30 m deep. Three distinct assemblages of invertebrates were identified based on depth and/or stability of the sediments:
    - Deeper stations and areas of increasing substrate stability on the canyon ridge had an assemblage comprised of polychaete worms (A*maeana occidentalis, Nothria elegans, Lumbrineris luti*) and crustaceans (*Paraphoxus daboius, Euphilomedes oblonga, E. carcharodonta*);
    - Shallow stations and areas of decreasing substrate stability along the canyon ridge had an assemblage comprised of polychaete worms (*Dispio uncinata*, *Scoloplos armiger, Onuphus erimita, Paraphyoxus lucubrans*), cumaceans, and the mollusk *Olivella* spp.;
    - Intermediate depths and areas of intermediate substrate stability along the ridge gradient had an assemblage comprised of the crustacean *Euphilomedes longiseta*, the bivalve *Tellina modesta*, and the sand dollar *Dendraster excentricus*.

- **Megafaunal Invertebrates in Ascension and Carmel Canyon** (Bianchi 2011). The manned submersible *Delta* was used to survey megafaunal invertebrates during 12 dives in Ascension Canyon (182-319 m) and 12 dives in Carmel Canyon (90-305 m).
    - **Ascension Canyon:** The brittle star (Ophiacantha) was the most abundant taxon and was common in substratum types containing boulders, boulder-mud, boulder-cobble, and mud-cobble. The second most abundant taxon, the hermit crab, was distributed evenly across all substratum types. The third most abundant taxon, the psolid sea cucumber, was distributed in mixed substratum consisting of boulders and mud. The fourth and fifth most abundant taxa were the fragile pink urchin (*Allocentrotus fragile*) and the crinoid (*Florometra serratissima*), which were common on all substratum types, except cobble-boulder.
    - **Carmel Canyon:** The spot prawn (*Pandalus platyceros*) was the most abundant taxon and was observed in mud-pebble and mud substratum types. The second most abundant taxon, the brittle star, was distributed across mixed boulder-mud substratum types. The third, fourth and fifth most abundant taxa were squat lobsters (Galatheidae), crinoids, and vermillion sea stars (*Mediaster aequalis*) and were distributed across all substratum types.

  Note: See 'Biogenic Habitat' section above for more additional information on the rank abundance of structuring-forming megafaunal invertebrates.
- **Invertebrates in Submarine Canyons in Central and Northern California** (Airamé et al. 2003).
    - Clams and worms burrow into the hard mud outcrops on more stable canyon walls.
    - Articulated brachiopods (*Laqueus californianus var. vancouveriensis*) are found on canyon walls at depths of 500-700 m.
    - Feather stars (*Florometra serratissima*) occur at depths of 30-1000 m on rocky ridges in the Monterey Bay and on the edges of the canyon slope.
    - Mushroom corals (*Anthomastus ritteri*) live in sediments and rocky walls at depths of 360-1200 m.
    - Predatory tunicates (*Megalodicopia hians*) occur in dense aggregations in areas of mixed rock and mud.
    - Sea pens (*Umbellula lindahl*i) are found on soft sediments at depths below 500 m throughout the Monterey Canyon.
    - Sea cucumbers, *Echinocucumis hispida* and *Ypsilothuria bitentaculata*, are the most abundant invertebrates in Pioneer Canyon.
    - One species of brittlestar (*Ophiocantha pacifica*) and one species of asteroid (*Eremicaster gracilis*) were found in both Monterey and Pioneer Canyons.
- **CBCs in Monterey Bay**: In the Monterey Bay region, CBCs were observed most commonly on steep slopes, such as the walls of Monterey Canyon, where recent seafloor erosion is likely to have occurred (Paull et al. 2005a). The biologic communities associated with 4 CBCs in the Monterey Bay region, 2 of which were located in Monterey Canyon, were described by Barry et al. (1996) and is summarized in the Chemosynthetic Biological Communities habitat section of this report.

- **Demersal Fish in Ascension Canyon** (Bizzarro et al. 2003). Seafloor features and fish assemblages were surveyed using the Delta submersible along 50 meter depth contours, between 200 and 350 m in Ascension Canyon. The five most abundant fish species at each depth were (listed in order of decreasing abundance):
  - 200 m: stripetail rockfish, greenstriped rockfish, *Sebastes* spp. (rockfishes), Pleuronectiformes (flatfishes), Agonidae (poachers);
  - 250 m: stripetail rockfish, *Sebastomus* spp., *Sebastes* spp.(rockfishes), Pleuronectiformes (flatfishes), greenstriped rockfish;
  - 300 m: Pleuronectiformes (flatfishes), rex sole, blackbelly eelpout, bank rockfish, Dover sole;
  - 350 m: Dover sole, eelpouts, rex sole, shortspine thornyhead, splitnose rockfish.
- **Demersal Fish in Soquel Canyon** (Yoklavich et al. 2000). Using strip transects that covered an estimated 33,754 m^2 in Soquel Canyon (depth range 80-360 m), a total of 6,208 non-schooling fishes were observed representing at least 52 species. Rockfishes represented 77% of the total number of individuals, and included a minimum of 24 species. The most abundant taxa observed during this study included: poachers, Pacific hagfish, Pacific hake, Dover sole, lingcod, shortspine thornyhead, and rockfishes (stripetail, bocaccio, rosethorn, greenspotted, greenstriped, darkblotched, halfbanded, cowcod, pygmy, yelloweye, canary, greenblotched, bank, widow, yellowtail). Six distinct habitat guilds of fishes were determined using habitat-based clustering analysis:
  - Mud: stripetail rockfish, Dover sole, poachers, shortspine thornyhead;
  - Cobble-Mud/Mud-Pebble: halfbanded rockfish, greenstriped rockfish, greenspotted rockfish, pygmy rockfish;
  - Mud-Cobble/Mud-Rock: stripetail rockfish, rosethorn rockfish, poachers, greenspotted rockfish, greenstriped rockfish;
  - Boulder-Mud: rosethorn rockfish, greenspotted rockfish, bocaccio;
  - Mud-Boulder/Rock-Mud/Rock ridge: bocaccio, rosethorn rockfish, greenspotted rockfish;
  - Rock-Boulder: pygmy rockfish, bocaccio.
- **Fishes in Submarine Canyons in Central and Northern California** (Airamé et al. 2003).
  - Rattails and whiptails (Macrouridae) are common fishes at depths of 200-6000 m. Three species of macrourids (*Coryphaenoides armatus, C. filifer, and C. leptolepis*) are the most common fishes in Pioneer Canyon.
  - Flatfishes, including Dover sole (*Microstomus pacificus*), English sole (*Pleuronectes vetulus*), petrale sole (*Eopsetta jordani*), rex sole (*Errex zachirus*), and deep-sea sole (*Embassichthys bathybius*), are found on sand and mud bottoms in submarine canyons.
  - Adult rockfishes (*Sebastes* spp.) are commonly associated with some structure, such as rocky cliffs, ledges, talus slopes, and cobble and boulder fields.

    - Sablefish (*Anoplopoma fimbria*) are concentrated from 400-600 m in submarine canyons.

- **General Classification of California Marine Fishes** (Allen and Pondella 2006). The authors used cluster analysis to determine which species occur together and in different habitats (by substrate type, depth, and latitude). Most of the species that are found in submarine canyons also occur in shelf, slope and rise habitats outside of canyons. One species group, composed of boccacio, bank, greenspotted, chilipepper, and rosethorn rockfish, was strongly associated with deep reef and submarine canyon habitats.

Species Composition Shifts:

- **Natural Changes:** Sediment flows and food falls deliver natural supplies of food to deep canyon habitats, which in turn rapidly change the species compositions at these depths.
    - **Flushing events, landslides and other sediment flows** down the canyon head or walls can dislodge or bury sessile and sedentary infaunal and epifaunal invertebrates and temporarily alter the species composition. Opportunistic species - species that disperse widely, colonize rapidly, and reproduce quickly - are most common after a disturbance event.
    - **Food Falls**: Mobile invertebrates and a few species of fish rapidly colonize mats of macrophyte detritus. Comparative studies (Vetter and Dayton 1998, 1999; Okey 2003) have found substantial benthic community differences between algae patches and background sediment. Whale falls also alter the species composition of benthic habitats in submarine canyons (Smith and Baco 2003). Whale carcasses in the deep ocean off California may pass through three to four overlapping successional stages and this successional process may occur rapidly, in less than 10 years (Lundsten et al. 2010). The majority of species at Monterey Canyon whale fall communities are common deep-sea inhabitants of Monterey Canyon, nearby seamounts, and the continental slope. See "Slope – Soft Bottom" habitat summary for additional information.
- **Human-Induced Changes:** A variety of human activities can alter species composition in submarine canyons.
    - **Structure-forming Invertebrates**: Structure-forming invertebrates are very susceptible to damage from physical structures dragged across the seafloor including anchor lines and fishing gear. Bottom trawling gear poses the biggest threat, but other gears with smaller footprints include bottom longline, pot/trap and hook-and-line gear. Two areas with relatively high coral concentrations are the shelf break and the Monterey Canyon (Morgan et al. 2005). These areas appear to have more corals because they have been lightly fished. Heavily fished areas have fewer corals.
    - **Rockfish** (Yoklavich et al. 2000). Sites in Soquel Canyon that were less fished had larger fishes and significantly higher abundances of major commercial and recreational species compared to sites that were more fished. Less fished sites were dominated by less valuable, small, benthic rockfish species. Rockfishes in the study area are likely protected from excessive harvest because the habitat characteristics make it difficult for fishermen to locate and target fishes.

Species Diversity and Species Richness: Species richness and diversity may be elevated in submarine canyons in comparison to the shelf or slope habitat adjacent to canyons. Increased heterogeneity of the substrate, steeper topography, and increased delivery of organic matter (e.g., macrophyte detritus) may be partially responsible for this pattern.

- **Infaunal Invertebrates** (Vetter and Dayton 1998). Species diversity of infauna was generally high in submarine canyons, but tended to increase with depth. However, when compared to sites at the same depth on the shelf or slope, species diversity was lower at canyon sites (especially at shallower depths). Species richness was similar between sites inside and outside canyons.
- **Megafaunal Invertebrates in Ascension and Carmel Canyon** (Bianchi 2011). The species richness and species diversity of the megafaunal invertebrate assemblage was determined for Ascension Canyon (182-319 m) and Carmel Canyon (90-305 m). The species richness index (S) was 47 for Carmel Canyon and 42 for Ascension Canyon. Mean species diversity index (H' calculated at patch level) was 1.7 for Carmel Canyon and 1.5 for Ascension Canyon.
- **Megafauna** (Vetter and Dayton 1999). Species richness of all megafauna was greater at sites inside canyons than outside canyons on the shelf and slope. Species richness of fishes was greater in the canyons at all depths for which comparative data were available (100 to 500 m).
- **Demersal Fish in Ascension Canyon** (Bizzarro et al. 2003). Significantly higher species diversity was observed along the southern wall of the canyon in association with more heterogeneous habitat. Species diversity was significantly higher at 300 and 350 m.
- **Whale Falls**. Local species diversity (mean of 185 macrofaunal species) on large whale skeletons during the sulphophilic stage is higher than in any other deep-sea hard substratum community (Smith and Baco 2003). Global species richness on whale falls (407 species) is also high compared with cold seeps and rivals that of hydrothermal vents (469 species worldwide). The majority of species at Monterey Canyon whale fall communities are common deep-sea inhabitants of Monterey Canyon, nearby seamounts, and the continental slope (Lundsten et al. 2010). Upon initial arrival, whale carcasses host a relatively low-diversity community of mobile scavengers. Through time, diversity increases; however, most of the increases in species richness come from background taxa that exploit abundant nutrients provided by the carcass.

Biomass: The abundance of many groups of organisms is elevated in association with submarine canyons. Increased delivery of organic matter (e.g., macrophyte detritus) may be partially responsible for this pattern for demersal species. Some species of harvested species may be more abundant in submarine canyons because the steep topography and habitat heterogeneity may decrease the efficiency of gear or cause it to become entangled. The heads of submarine canyons may concentrate schooling prey species that undergo diel vertical migrations making these areas foraging hotspots for predators such as seabirds and mammals.

- **Megafaunal Invertebrates in Ascension and Carmel Canyon** (Bianchi 2011). The density of megafaunal invertebrates was assessed in Ascension Canyon (182-319 m) and Carmel Canyon (90-305 m).

- **Ascension Canyon:** The overall mean density of megafaunal invertebrates was 56/100 m^2 and 94/100 m^2 at mid-shallow (148-234 m) and mid-deep (234-320 m) depths, respectively. The *Ophiacantha* brittle star was the most abundant taxon with an overall density of 25/100 m^2. Hermit crabs, the second most abundant taxon, was densest in mid-deep depths (29/100 m^2). The third most abundant taxon, the psolid sea cucumber, was densest in mid-deep depths (14/100 m^2).
- **Carmel Canyon**: The overall mean density of megafaunal invertebrates was 251/100 m^2, 211/100 m^2, and 254/100 m^2 at shallow (<148 m), mid-shallow (148-234 m), and mid-deep (234-320 m) depths, respectively. The spot prawn (*Pandalus platyceros*) was the most abundant taxon and was densest in mid-shallow depths (61/100 m^2). The second most abundant taxon, the *Ophiacantha* brittle star was densest in mid-deep depths (68/100 m^2). The third most abundant invertebrate, the squat lobster (Galatheidae), was densest in mid-deep depths (103/100 m^2). The fourth and fifth most abundant taxa were crinoids and vermillion sea stars (*Mediaster aequalis*) with densities at shallow depths of 97/100 m^2 and 29/100 m^2, respectively.

- **Invertebrates and Fishes in La Jolla and Scripps Canyons** (Vetter and Dayton 1998, 1999). The density and biomass of infaunal invertebrates were higher in the canyons than outside at all depths where comparative data were available (100-500 m). Biomass in the canyons was highest at 310 m and lowest at 700 and 900 m. Density in the canyons was highest at 100 m and generally declined with increasing depth. Canyons support large populations of macrofaunal crustaceans, which in turn support large numbers of fishes. Abundance of non-urchin megafauna was greater in the canyons than out. Abundance of fishes was greater in the canyons at all depths for which comparative data were available (100 to 500 m).
- **Demersal Fish in Soquel Canyon** (Yoklavich et al. 2000). Sites that were less fished had larger fishes and significantly higher abundances of major commercial and recreational species (e.g., lingcod and greenspotted, cowcod, greenblotched, yelloweye, bocaccio, darkblotched, and bank rockfish).
- **Harvested Species:** Recreational and commercial harvest removes biomass of targeted fish and invertebrate populations. For some targeted species, biomass is substantially reduced compared to unfished biomass levels (Tables 3 and 4). Though extraction is the primary reason for a reduction in biomass for many species, changing oceanographic and ecological conditions are an important contributing factor for some harvested species. For the majority of the 10 invertebrate and 156 fish stocks landed in MBNMS, the status of the stock has not been assessed (Tables 3 and 4).

MOVEMENT AND DISPERSAL

The axis of the submarine canyon may serve as a migratory corridor for mobile species. Some species may move up or down the canyon for seasonal migrations (e.g., feeding or breeding migrations). Some species may progressively move down the canyon as they grow older and larger (i.e., ontogenetic migration).

- **Prickly Sharks** (Starr et al. 1999). The movements of prickly sharks captured in Monterey Canyon were followed for up to 3 months. During that time, sharks moved frequently and ranged in depth from as little as 5 m of water near the canyon head to as deep as 375 m at a distance of 10 km offshore. Preliminary analyses indicated four patterns of daily activity: (1) at the canyon head at night and in deep water during the day, (2) in deep water at night and at the canyon head during the day, (3) at the canyon head the entire day, and (4) completely absent from the canyon head. The reasons for these movement patterns are not known.

- **Adult Bocaccio** (Starr et al. 2002b). Of the 16 bocaccio tagged in 1998 in the Monterey Canyon, 10 spent less than 10% of the study time in the approximately 12-km^2 study area. One fish stayed in the study area for about 50% of the study time. Signals from the remaining 5 fish were recorded in the study area the entire time. Bocaccio frequently moved vertically 10-20 m and occasionally displayed vertical movements of 100 m or greater.
- **Adult Greenspotted Rockfish** (Starr et al. 2002b). Fish tagged in 1997 in the Monterey Canyon exhibited almost no vertical movement and showed limited horizontal movement. Two individuals spent more than 90% of the time in a 0.58-km^2 area. Three others spent more than 60% of the time in a 1.6-km^2 area, but displayed frequent horizontal movements of at least 3 km.

SPECIES OF SPECIAL INTEREST

Many species of special resource management interest are associated with submarine canyons in MBNMS Tables 3-7.

- ***Species Landed in MBNMS*:** Of the 10 invertebrate and 156 fish species that are commonly caught and sold in the commercial and/or recreational fisheries of MBNMS (Starr et al. 2002a), two invertebrates (box crab and red rock crab) and 41 fishes occur in canyons.
- ***Endangered and Threatened Species:*** There are no known endangered or threatened invertebrate species in the federal waters of MBNMS. No endangered or threatened fish species in the sanctuary are associated with submarine canyons. The leatherback turtle is the only endangered reptile to occur regularly in the sanctuary and it is commonly sighted over submarine canyons. All 3 of the listed seabirds and 7 of the 10 listed marine mammals are commonly sighted over submarine canyons.
- ***Other At-Risk Species:*** None of the invertebrate taxa in the federal waters of MBNMS are considered to be at-risk. Five at-risk fishes occur in canyons. The leatherback turtle, along with all 11 at-risk birds and 6 of the 9 at-risk mammals appear to be associated with canyons.

Additional species of special resource management interest associated with submarine canyons include:

- Structure-forming invertebrates, such as corals and sponges, due to their important ecological role in creating habitat structure and their vulnerability to disturbance from human activities;

- Krill due to their important ecological role as a primary food source for seabirds, marine mammals and fishes;
- Sooty Shearwaters which reach extremely high densities during the summer, when hundreds of thousands of adults forage for fishes and squid in sanctuary waters after migrating from the southern hemisphere;
- Seabirds (e.g., Rhinoceros Auklets) and marine mammals (e.g., elephant seals, California sea lion) vulnerable to disturbance, injury or death from human activities in the sanctuary such as oil spills and entanglement in fishing gear.

Seamount

HABITAT OVERVIEW

Seamounts are mainly volcanic in origin, rise to considerable height from great depths along the continental rise, and are limited in length across the summit. Their vertical nature and rocky substrate create habitat complexity and support a very different biological assemblage than the soft bottom that typically surrounds them. Seamount rocky outcrops, particularly near peaks, are inhabited by a suite of deep-sea corals and sponges that are typically absent or quite rare in more typical ocean settings.

Several seamounts - including Gumdrop, Pioneer, Guide, and Davidson Seamounts - occur off central California (Figure 3). On June 12, 2000, President Bill Clinton directed the National Oceanic and Atmospheric Administration (NOAA) to work in partnership with marine research institutions and universities to explore Davidson Seamount.

Assemblages of large corals and sponges, along with many associated animals such as sea stars, anemones, crustaceans, octopus and fishes, are common on Davidson Seamount. Explorations in 2002 and 2006 observed 18 species new to science. Ecological processes influencing the distribution, abundance and dynamics of seamount fauna are less well known than more accessible ecosystems such as kelp beds and corals reefs.

Though relatively close to shore and one of the largest seamounts on the West Coast, Davidson Seamount appears to be relatively pristine, based on observations of biological communities during submersible explorations in the past decade. By comparison, observations of various other seamounts worldwide indicate severe damage by trawling - a fishing practice that can decimate coral assemblages and may require decades or centuries to recover.

In March of 2009, NOAA expanded MBNMS to include the Davidson Seamount Management Zone (DMSZ), an area encompassing 775 square miles. Davidson Seamount is the first seamount to be protected within a United States national marine sanctuary.

Geological Structure and Origin of Seamounts in central California

Gumdrop, Pioneer, and Guide Seamounts are located about 120 kilometers off the California margin, north of Monterey Bay (Figure 3). They have a similar geological structure and origin to Davidson Seamount, which is located 120 kilometers due west of San Simeon. Davidson, Guide, Pioneer, and Gumdrop Seamounts have only recently been described as an atypical type of oceanic volcanism, having northeast-trending ridges that reflect the ridge-parallel structure of the underlying crust (Davis et al. 2002). Unlike most intra-plate ocean island volcanoes, the seamounts are built on top of spreading center segments that were abandoned at the continental margin when the tectonic regime changed from subduction to a transform margin (Davis et al. 2007).

- **Gumdrop Seamount** (Davis et al. 2002, MBARI 2009a). The northernmost of the three seamounts, has a series of aligned cones separated by sediment-filled troughs, but these structures are poorly defined. The shallowest cone rises to 1,207 meters below sea level. The volume, estimated at about 100 km^3, is difficult to determine because the base of the seamount is poorly defined. Samples have been recovered to age the seamount, but their age has not been determined.

- **Pioneer Seamount** (Davis et al. 2002, MBARI 2009a). Pioneer Seamount is nearly equidimensional with width and length of about 12.8 kilometers. It rises about 1,930 meters above the surrounding seafloor to a minimum water depth of 820 meters. It has a volume of about 135 km^3. The seamount is 11.0 ± 0.1 million years old.
- **Guide Seamount** (Davis et al. 2002, MBARI 2009a). Guide Seamount looks virtually identical to Davidson Seamount, except it is smaller (approximately 16.5 kilometers by 5 kilometers). It rises about 1,440 meters above the surrounding seafloor and reaches a minimum water depth of 1,682 meters. The volume above the surrounding seafloor is about 130 km^3. The seamount is 16.6 ± 0.5 million years old. The seamount consists of four, nearly parallel volcanic ridges, separated by sediment-filled troughs, aligned parallel to magnetic anomalies in the underlying ocean crust and therefore parallel to the abandoned mid-ocean ridge that formed the crust.
- **Davidson Seamount** (Davis et al. 2002, MBARI 2009a). Davidson Seamount is the largest of the central California seamounts, 42 kilometers long and 13 km wide. It rises 2,280 meters above the surrounding seafloor to a minimum water depth of 1,250 meters. It is almost as large as Guide, Pioneer, and Gumdrop Seamounts combined, with an estimated volume of 320 km^3. Davidson Seamount, like Guide, Pioneer, and Gumdrop Seamounts, is an elongated structure with a distinctive northeast-to-southwest orientation. The seamount consists of about six subparallel linear volcanic ridges separated by narrow valleys that contain sediment. These ridges are aligned parallel to magnetic anomalies in the underlying ocean crust. The seamount is 12.2 ± 0.4 million years old and formed about 8 million years after the underlying mid-ocean ridge was abandoned.

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	See page 117
Feeding Ground:	No specific information was found on this topic in this habitat category.
Spawning Ground:	No specific information was found on this topic.
Migratory Corridor:	No specific information was found on this topic.
Biogenic Habitat:	See page 117
Energy Flow:	
Primary Production:	No information specific to primary production at seamounts was found during the literature review. General information on primary production on the slope can be found in the “Slope – Hard Bottom” habitat summary.
Benthic-Pelagic Coupling:	See page 118

Key Trophic Interactions:	Invertebrate communities at Davidson and Pioneer Seamounts are dominated by passive suspension-feeding cnidarians (mostly corals), and appear to be tightly coupled to habitat type (rugged slopes and peaks) (Lundsten et al. 2009a).
Key Trophic Cascades:	No specific information was found on this topic.
Productivity Hotspots:	See page 118
HABITAT STRUCTURE	
Species Composition:	See page 118
Species Composition Shifts:	See page 121
Species Diversity and Richness:	See page 121
Biomass:	No specific information was found on this topic.
Key Species Interactions	No specific information was found on this topic.
MOVEMENT AND DISPERSAL	See page 122
SPECIES OF SPECIAL INTEREST	See page 122

HABITAT SUMMARY

HABITAT FUNCTION

Functional Habitats

Nursery Habitat: Very little is known about the early life histories of local seamount communities. On several occasions, numerous skate egg cases found at Davidson Seamount were nested near, or attached to, deep-sea corals in apparent nursery areas (Ebert and Davis 2007; Andrew DeVogelaere, pers. comm.). The skate egg cases could not be identified, but a female broad skate (*Amblyraja badia*) was observed swimming in the vicinity of the collected cases (Ebert and Davis 2007).

Biogenic Habitat: Most of the organisms found at seamounts, such as corals and sponges, are large, sessile organisms. These structure-forming invertebrates are used by other sessile organisms as a hard substrate for attachment (e.g., basket stars, sea stars, scale worms, other corals, other sponges) and by some mobile organisms as shelter or food (e.g., fishes, skate egg cases, crabs, shrimps). There is increasing evidence that many areas of deep coral and sponge habitats function as ecologically important habitats for fishes and invertebrates (Hourigan et al. 2007).

- **Deep-sea Coral Habitat Suitability** (Guinotte and Davies 2012). The potential distribution of deep-sea corals was modeled for the U.S. West Coast Exclusive Economic Zone. Predicted habitat suitability in MBNMS is shown separately for 6 deep-sea coral taxa (Figure 10). Habitat suitability probabilities were highest at the Davidson Seamount for Suborders Calcaxonia, Alcyoniina, Scleraxonia, and Order Antipatharia. In contrast, suitability probabilities were lower at Davidson Seamount for Order Scleractinia and Suborder Holaxonia. However, the model will likely overpredict the amount of suitable habitat in some areas (e.g., indicate suitable coral habitat in areas that are known soft bottom regions) because fine-scale bathymetric features (10's of meters), substrate, and current data were not available for the entire study area.

Energy Flow

Benthic-Pelagic Coupling:

- **Drift Algae and Surfgrass**: Fronds shed by kelp growing on the rocky reef in nearshore waters <30 m may be transported by water currents to seamount habitats. Drift algae and surfgrass have been observed on the Davidson Seamount, including *Alaria marginata*, *Macrocystis* sp., *Nereocystis luetkeana*, and *Phyllospadix* sp. (Burton and Lundsten 2008). For more information, see the "Macroalgal Detritus" habitat summary.

Productivity Hotspots:

- **Seamounts as Larval Sources** (McClain et al. 2009). Seamount environments may represent optimal habitats for particular faunal groups resulting in thriving and dense populations encountered only rarely in other habitats. Based on research at Davidson Seamount and nearby Monterey Canyon, preliminary evidence suggests seamount communities may serve as a source of larvae for non-seamount habitats.
- **Hydrographic Features at Davidson Seamount** (Rizk 2006; Lundsten 2007). The topographic features of Davidson Seamount may affect circulation patterns of the California Current and California Undercurrent, perhaps trapping meanders over the seamount. In the summer of 2000, an onshore intrusion of the California Current remained directly over the Davidson Seamount from June through September. In addition, low frontal probabilities are seen upstream of Davidson, perhaps indicating a Taylor column or similar feature. These seamount-current interactions may enhance productivity at, and above, the seamount.

HABITAT STRUCTURE

"Distribution, diversity, and abundance of benthic organisms on seamounts has been attributed to various factors, including substrate type, local hydrographic conditions, reproductive modes, proximity to sources of larvae, geographic location, seamount topography, entrapment of migrating zooplankton, and elevated current velocities" (Lundsten et al. 2009a).

Species Composition: Demersal fishes and invertebrates on seamounts tend to be distributed according to depth and bottom type. Invertebrate communities at Davidson and Pioneer Seamounts are dominated by passive suspension-feeding cnidarians (mostly corals; Lundsten et al. 2009a). There is a high similarity among seamount fish fauna at similar depths of Davidson and Pioneer Seamounts, with a shift from provincial to abyssal/cosmopolitan species with increased depth (Lundsten et al. 2009b). There is no evidence of endemism among megafauna at Davidson or Pioneer Seamounts (Lundsten et al. 2009a,b; McClain et al 2009).

- **Davidson Seamount Taxonomic Guide** (Burton and Lundsten 2008). In 2002 and 2006, MBNMS led two multi-institutional expeditions to characterize the geology and natural history of Davidson Seamount. Approximately 140 hours of video and sample collections were taken during 17 remotely operated vehicle (ROV) dives. Most were primarily on the seafloor, with opportunistic dives in the water column above the seamount. At least 237 taxa were observed, including 18 previously undescribed species (Erica Burton, pers. comm.; 8 sponges, 1 hydroid, 4 corals, 1 ctenophore, 1 nudibranch, 1 polychaete, 1 sea star, 1 tunicate). See Table 17 for a list of species observed at Davidson Seamount.

- **Benthic Invertebrates at Davidson and Pioneer Seamounts** (Lundsten et al. 2009a). Abundance and distribution of benthic megafaunal invertebrates found on three seamounts, Davidson and Pioneer off central California and Rodriguez off southern California, are described. Video observations were taken during 27 remotely operated vehicle (ROV) dives and annotated. Video analysis yielded 134,477 observations of 202 identified invertebrate taxa. Video transects were analyzed to quantify organism density. Thirteen new species were observed and collected. See Table 18 for observed frequencies of benthic invertebrates at Davidson and Pioneer Seamounts.
    - Cnidaria, Porifera, and Echinodermata are the dominant phyla of megafaunal invertebrates at Davidson and Pioneer Seamounts.
    - Cnidarians are most frequently observed phylum at each seamount; deep-sea corals dominate cnidarian observations.
    - Sponges were observed more frequently at Davidson Seamount than at Pioneer Seamount.
    - Crinoid echinoderms dominated megafaunal echinoderm observations at both seamounts.
- **Invertebrate Depth Zonation at Davidson Seamount** (McClain et al. 2010). In 2006, 33 quantitative video transects were collected by ROV on Davidson Seamount (1246–3656 m). Bathymetric variation in benthic megafauna was examined.
    - Invertebrate species composition and relative abundance shift significantly with depth. A 50% change in assemblage composition occurs approximately every 1500 m. Species turnover is considerable across the flanks of the seamount (up to 70%). In addition, the summit and base assemblages of Davidson Seamount share as little as 20-30% of their species.
    - Three distinct zones correspond to the summit, flanks, and base of the seamount; zonation patterns appear to be driven by changes in octocorals, hexactinellids, asteroids, and crinoids.
- **Fishes at Davidson and Pioneer Seamounts** (Lundsten et al. 2009b). Abundance and distribution of demersal fishes found on three seamounts, Davidson and Pioneer off central California and Rodriguez off southern California, are described. Video observations were taken during 27 remotely operated vehicle (ROV) dives and annotated. Video analysis yielded 2,151 observations of 36 identified taxa. Video transects were analyzed to quantify organism density. See Table 19 for observed frequencies of dominant fishes at Davidson and Pioneer Seamounts.
    - Depth seems to be the most significant factor structuring fish communities at Davidson and Pioneer Seamounts

    - Distribution, abundance, and natural history of fish assemblages inhabiting Davidson and Pioneer Seamounts support the notion that these communities can be distinct from those of non-seamount habitats, especially faunas of deeper seamount (i.e., Davidson), which may contain more rare abyssal and cosmopolitan species.

- **2000 Aerial Survey at Davidson Seamount** (Forney 2002). In July 2000, an aerial survey was conducted to provide background information about the occurrence of marine mammals, seabirds, sea turtle, sharks, and ocean sunfish over Davidson Seamount. Systematic observations were made by flying nine, 15-20 nautical mile-long transect lines. During the 135-180 nautical miles of aerial transect surveys over the Davidson Seamount, one sighting of each was observed: Risso's dolphin (*Grampus griseus*), Black-footed Albatross (*Phoebastria nigripes*), and ocean sunfish (*Mola mola*) (Table 20).

- **2009 Aerial Survey at Davidson Seamount** (CINMS, unpubl. data). In April 2009, Channel Islands National Marine Sanctuary staff conducted an aerial survey of Davidson Seamount. The survey transect spanned a total of 136 linear nautical miles, covering approximately 264 square nautical miles. A total of 10 unidentified pinnipeds, and a single sperm whale were observed (Table 20).

- **2010 Aerial Surveys at Davidson Seamount** (King and DeVogelaere, MBNMS, unpubl. data). In 2010, MBNMS staff conducted two aerial surveys of the surface waters over Davidson Seamount. On January 14, 2010, approximately 542 kilometers of "on effort" transects were flown in five zig zag formations to the north, south, east, and west over Davidson Seamount. On April 19, 2010, five transects were flown perpendicular to the main axis of Davidson Seamount, totaling approximately 400 kilometers of "on effort" transects. (Table 20) provides a list of the species observed in the surface waters of the DSMZ.

    - In January 2010, 139 individual animals were observed, for an individual encounter rate of 0.26 animals per kilometer, 0.20 seabirds per kilometer, and only 0.04 marine mammals per kilometer.

    - In April 2010, 78 individual sightings were recorded, totaling 336 individual animals for an individual encounter rate of 0.84 animals per kilometer and 0.79 marine mammals per kilometer.

- **2002 Ship-based Survey at Davidson Seamount** (Benson 2002). In May 2002, visual ship-based surveys of the sea surface were conducted for seabirds, marine mammals, and surface-active fishes. Eight species of marine mammals, 15 seabird taxa, and two surface-active fishes were sighted during this investigation (Table 20).

    - Dall's porpoise (*Phocoenoides dalli*) and Black-footed Albatross (*Phoebastria nigripes*) were the most commonly sighted organisms encountered over the Davidson Seamount.

    - The most abundant organisms were the Black-footed Albatross, Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Northern right whale dolphin (*Lissodelphis borealis*), and Dall's porpoise.

- **2010 Ship-based Survey at Davidson Seamount** (Newton et al. 2011). In July 2010, MBNMS staff conducted a ship-based survey of the waters above and around the Davidson Seamount. Eight transect lines were surveyed for a total of 605 km of “on-effort” observations. Seventeen species of seabirds and 6 marine mammal species were observed (Table 20).
    - Cook’s Petrel (*Pterodroma cookii*) was the most abundant seabird observed (8.4 birds/km^2), followed by Leach’s Storm-petrel (*Oceanodroma leucorhoa*; 5.6 birds/km^2).
    - Of a total of 200 marine mammal sightings, fin whales (*Balaenoptera physalus*) were the most commonly encountered marine mammals (51% of sightings), comprising 94% of whales sighted.

Species Composition Shifts:

- **Natural Changes:** The seamounts off central California have only recently been studied, and there are no long-term data to determine changes in species composition over time.
    - **Species composition at Davidson Seamount** (McClain et al. 2010). A significant shift in species composition and relative abundances of species occurs with depth. A 50% change in composition is observed for approximately every 1500 m. Davidson Seamount summit and base assemblages share as little as 20–30% of their species. A consistent bathymetric gradient in compositional change occurs across the flanks of the seamount. In addition, transects group into three distinct depth zones that correspond to the summit, flanks, and base of Davidson. Much of the compositional pattern appears to be driven by compositional changes in octocorals, hexactinellids, asteroids, and crinoids, with hexactinellids contributing the most to bathymetric variation in species dominance.
- **Human-induced Changes:** Many benthic species on seamounts are long-lived and slow-growing, and not resilient to human impacts (Clark et al. 2010). Deep-seas coral and sponge communities on seamounts, like all benthic biogenic habitats, are susceptible to degradation from human activities that disturb benthic habitats such as fishing with bottom-tending gear, and laying physical structures (e.g., cables). Studies from around the world have reported severe disturbance to deep coral communities from trawling (Hourigan et al. 2007). Removal of, or damage to, biogenic habitats has the potential to temporarily or permanently alter species compositions at seamounts. The Davidson Seamount appears to be relatively pristine (DeVogelaere et al. 2005); however, it has only recently been studied, and there are no long-term data to determine changes in species composition. The use of bottom contact fishing gear has been prohibited in the DSMZ by an Essential Fish Habitat Conservation Area, which was implemented in 2006 by NOAA’s National Marine Fisheries Service and the Pacific Fisheries Management Council. Take or disturbance (by methods other than fishing) of any resource below 3000 feet within the DSMZ is regulated by MBNMS.

Species Diversity and Species Richness:

- **Assemblage structure at Davidson Seamount** (McClain et al. 2010). Species diversity and density at Davidson Seamount do not significantly change with depth, and can vary greatly on a single isobath. Authors suggest the lack of clear bathymetric signal in diversity or density may reflect the proximity of Davidson to highly productive coastal waters fueled by coastal upwelling. However, results indicate that considerable species turnover, upwards of 70%, can occur across the flanks of an individual seamount (see Species Composition Shifts).

MOVEMENT AND DISPERSAL

Seamount environments may represent optimal habitats for particular faunal groups resulting in thriving and dense populations encountered only rarely in other habitats. Based on research at Davidson Seamount and nearby Monterey Canyon, preliminary evidence suggests seamount communities may serve as a source of larvae for non-seamount habitats (see McClain et al. 2009).

SPECIES OF SPECIAL INTEREST

Many species of special resource management interest are found at Davidson Seamount (Tables 17, 20).

- ***Species Landed in the MBNMS*****:** Two invertebrates (market and Humboldt squids) and three fish taxa (Pacific grenadier, ocean sunfish, shortspine thornyhead) that are commonly caught and sold by commercial and/or recreational fisheries within MBNMS are observed at Davidson Seamount (Table 17). Although few species observed on and around seamounts are currently landed, some deep-water species might be targeted in the future (e.g., other grenadiers).
- ***Endangered and Threatened Species:*** There are no known endangered or threatened invertebrate or fish species at Davidson Seamount. Of the 22 bird and 19 mammal taxa observed over Davidson Seamount (Table 20), one bird (Xantus's Murrelet) is threatened and three mammals (humpback, fin, and sperm whales) are endangered.
- ***Other At-Risk Species:*** Ten "At-Risk" taxa have been observed at Davidson Seamount. One fish species (shortspine thornyhead) is listed as endangered by the IUCN (Table 17). Six birds are listed by the IUCN, of which one is endangered and five are vulnerable. Three mammals are listed by the IUCN, of which one is endangered and two are vulnerable (Table 20).

Additional species of special resource management interest at Davidson Seamount include:

- Structure-forming invertebrates, such as the many species of corals and sponges that have been observed at Davidson Seamount (Table 17), due to their important ecological role in creating habitat structure and their vulnerability to disturbance from human activities.

Oxygen Minimum Zone

HABITAT OVERVIEW

Respiration by organisms reduces the concentration of dissolved oxygen in the water column. In the photic zone of the water column (<200 m), photosynthetic organisms produce oxygen, which generally offsets respiration. However, in deeper and darker waters, oxygen production is reduced and respiration is high, subsidized by the decomposition of sinking organic matter from the photic zone above. This combination results in an oxygen-minimum layer, where dissolved oxygen is below 0.5 ml per liter. This oxygen minimum zone (OMZ) typically occurs at depths from 600 to 1000 m deep (Figure 5). Oxygen concentration in the water column decreases rapidly approaching the upper boundary of the OMZ, continues to decline until a minimum is reached in the middle of the OMZ, and then gradually increases with depth to the lower boundary of the OMZ and beyond. The OMZ influences both the vertical distribution of pelagic fauna, and where the OMZ intersects the seafloor (Figure 4), the depth distribution of benthic fauna.

Several studies have provided estimates of the depth of the OMZ off central California: 500-1,000 m based on studies in the area between Pt. Lobos and Pt. Sur (Mullins et al. 1985, Thompson et al. 1985 (based on Broenkow and Greene 1981)); 600-1,000 based on studies at Purisima Pt. (Hunter et al. 1990), Smooth Ridge (Vetter et al. 1994), and the area between Pt. Sur to Pt. Conception (Jacobson and Vetter 1996); and 500-1,130 m based on a study in Monterey Bay (MBARI 2009b). For the purpose of this report, we generally refer to 600 m as the upper bound and 1,000 m as the lower bound of the OMZ in central California.

However, it appears that the boundaries of the OMZ in the California Current System have been expanding during the last several decades and this expansion is predicted to continue as the climate warms (reviewed in Gilly et al. 2013). Shoaling of the upper boundaries of the OMZs, which accompanies OMZ expansion, leads to decreased oxygen at shallower depths and can affect both pelagic and benthic organisms through direct and indirect mechanisms. Effects include altered microbial processes and changes in predator-prey dynamics. Although some species will be negatively affected by these changes, others may expand their range or exploit new niches.

SEARCH TOPIC TABLE

TOPIC FRAMEWORK	
Functional Habitats:	
Nursery Habitat:	No specific information was found on this topic.
Feeding Ground:	See page 124
Spawning Ground:	See page 125
Migratory Corridor:	See “Movement and Dispersal” section on page 131

Biogenic Habitat:	No information specific to biogenic habitat in the OMZ was found. See the "Biogenic Habitat" section in the Slope-Hard bottom, Slope-Soft Bottom and Chemosynthetic Biological Communities habitat summaries for related information.
Energy Flow:	
Primary Production:	No information specific to primary production in the OMZ was found. See Slope – Hard Bottom and Slope – Soft Bottom habitat summaries for related information.
Benthic-Pelagic Coupling:	No information specific to benthic-pelagic coupling in the OMZ was found. See Slope – Hard Bottom and Slope – Soft Bottom habitat summaries for related information. See Appendix III. Benthic-Pelagic Coupling for general information.
Key Trophic Interactions:	No information specific to key trophic interactions in the OMZ was found. Related information can be found in the Slope – Soft Bottom and Open Water habitat summaries.
Key Trophic Cascades:	No specific information was found on this topic.
Productivity Hotspots:	See page 125
HABITAT STRUCTURE	
Species Composition:	See page 126
Species Composition Shifts:	See page 128
Species Diversity and Richness:	See page 129
Biomass:	See page 130
Key Species Interactions	No information specific to key species interactions in the OMZ was found. See Slope – Hard Bottom and Slope – Soft Bottom habitat summaries for related information.
MOVEMENT AND DISPERSAL	See page 131
SPECIES OF SPECIAL INTEREST	No information specific to species of special interest in the OMZ was found. See Slope – Hard Bottom and Slope – Soft Bottom habitat summaries for related information.

HABITAT SUMMARY

HABITAT FUNCTION

Functional Habitats

Feeding Ground:

- **Deep Scattering Layer** (reviewed in Gilly et al. 2013). The upper boundary region of the OMZs (and the overlying Oxygen Limited Zone (OLZ)) is an important feeding ground in the California Current system. Vast amounts of micronekton, particularly krill and myctophid fishes, take refuge from visually oriented predators in this hypoxic region during daytime. These small organisms compress into discrete layers, called deep scattering layers, which often lie in the OLZs or near the upper (and lower) boundary of an OMZ. Dense aggregations of organisms in these deep scattering layers provide a rich daytime foraging ground for a wide variety of deep-diving pelagic predators, including swordfish, tunas, sharks, squid, elephant seals, and sperm whales.

- **Benthic Fishes**: The upper slope habitat between 600 and 1,200 m was identified by Wakefield (1990) as an important feeding ground for a diverse array of fishes, many of which utilize shallower nursery grounds on the shelf.

Spawning Ground: The OMZ appears to be an important spawning ground for a diverse array of fishes, many of which utilize shallower nursery grounds on the shelf and migrate down into the OMZ at later stages (Wakefield 1990). Dover sole, sablefish, and longspine and shortspine thornyhead, four of the most important species in the deepwater fishery off California, all have their peak spawning biomass in the depth range of the OMZ. Eliminating fishing deeper than 600-800 m would protect the spawning biomass of thornyheads, Dover sole, and sablefish (Jacobson and Vetter 1996).

- **Thornyheads in OMZ** (Jacobson and Vetter 1996). Peak spawning biomass for both thornyhead species off Oregon and central California (Point Sur to Point Conception) occurs in the OMZ depth range (600-1,000 m); longspine thornyheads are OMZ specialists that spend the entire benthic juvenile and adult phases in the OMZ. Small shortspine thornyheads are found in shallow water (200-600 m), but migrated to deeper water with growth.
- **Dover Sole** (Hunter et al. 1990). Ninety-eight percent of the spawning biomass of Dover sole (*Microstomus pacificus*) in central California (Half Moon Bay to Purisima Point) waters live in the OMZ between 640-1,005 m. Dover sole spawn at these depths and the eggs rise to the surface layers.
- **Giant Grenadier** (Novikov 1970). Male and female giant grenadier (*Albatrossia pectoralis*) live separately (females prefer ~300-700 m; and males prefer >~700 m). This separation is rarely disturbed. During spawning, females migrate to deeper depths (depths may be specific to the North Pacific). The spawning period for giant grenadier is prolonged and not confined to definite dates.

Energy Flow

Productivity Hotspots:

- **Edges of the Oxygen Minimum Zone**. Off central California (between Point Lobos and Point Sur), Thompson et al. (1985) found that benthic invertebrate density is significantly greater at the upper and lower edges of the OMZ (~525 and 1,025 m) with the pattern more pronounced at the upper edge. The peaks in faunal density corresponded with peaks in the organic carbon content of the sediment. They proposed that the peak in faunal density may be a response to high bacterial production where the oxycline intersects the bottom sediment. Mullins et al. (1985) proposed that the increase in biogeochemical activity along the edges of the OMZ in central California is due a combination of dissolved oxygen concentration, bottom currents, a bacterially-mediated nutrient recycling process, and food supplies. The nutrient recycling process involves an increase of biologically usable nitrate and nitrifying bacteria at OMZ edges and denitrifying bacteria at the core of the OMZ. The edges of the OMZs may be preferred sites of increased biological activity because of greater nutrient concentrations plus larger food supplies in the form of bacteria.

HABITAT STRUCTURE

Species Composition: Invertebrates and fishes are the numerically dominant animal groups in the OMZ. Species distributions appear to be influenced many factors including depth, sediment composition, and dissolved oxygen levels.

- **Infauna near Davenport** (John Oliver, MLML, unpubl. data). In northern Monterey Bay and off Davenport, sediment cores along transects have shown distinct infaunal species assemblages that vary by depth. The Oxygen Minimum Zone Group (700 m) is composed of *Byblis barbarensis*, *Ampelisca unsocalae*, *Myriochele gracilis, Gammaropsis ocellata*, *Phyllochaetopterus limicolus*, *Lepidepecreum kasatka*, *Photis typhlops*, *Scoloura phillipsi*, Nemertea, *Harpiniopsis epistomata*;
- **Invertebrates Near Smooth Ridge** (CSLC & MBNMS 2005). Soft-bottom, invertebrate faunal groups were studied at sites near Smooth Ridge ranging in depth from 25-885 m. Most of the biological resources that occur at in this area are found throughout the central California regions, especially at depths below 200 m where species tend to be cosmopolitan in distribution.
    - **Hard-bottom habitats:** The typical species assemblage between 300-1,000 m had a greater diversity and size of sponges and echinoderms than at shallower depths.
    - **Soft-bottom habitats:** 475 species of infaunal invertebrates were identified. Polychaete worms showed the highest abundance and species richness at most depths. Gammarid amphipods were relatively abundant at all stations, and were the most abundant species at 640, 770 and 795 m stations and the most species rich group at 640 and 770 m stations. Oligochaete worms were the most abundant taxa at 885 m station. Other groups relatively abundant on the slope included: caprellid amphipods (325 and 450 m); brittle stars (450 m); and bivalves (640 m).

      Sea pens, anemones, crabs and sea stars were the epifauna most commonly seen at all stations. Sea urchin, sea cucumber, and sea stars dominated between 280-449 m; sea pens, gastropods, and anemones dominated between 450-599 m; and sea pens, Tanner crab, snails, anemones, and sea cucumber dominated deeper than 600 m. Abundance of large invertebrates was highest at 325 and 885 m stations.
- **Infaunal Invertebrates 300-1,400 m** (Thompson et al. 1985). The infaunal community in central California (Point Lobos to Point Sur) as a whole is dominated by polychaete worms that lacked calcified tubes. Infaunal organisms with heavily calcified skeletons occurred throughout most of the study area, but at much lower abundance. The only water depth interval that lacked calcified infaunal organisms was 650 to 750 m, where oxygen concentrations drop below 0.3 ml/l O_2.
- **Megafaunal Invertebrates 300-1,400 m** (Thompson et al. 1985). Off central California (Point Lobos to Point Sur), all major invertebrate taxonomic groups were found to increase in numbers along both the upper and lower edges of the OMZ, while having minimum numbers within the OMZ.
    - Polychaetes were the most abundant individuals in all regions of the OMZ.
    - Echinoderms exhibited a distinct depth zonation with asteroids (most commonly the sun star, *Rathbunaster californicus*) dominating the upper OMZ boundary

(400-500 m), echinoids (dominated by irregular urchin *Brissopsis pacifica)* most abundant near the lower OMZ boundary (900 m), and ophiuroids (brittle stars) density peaking below the OMZ. The core of the OMZ (600-800 m) was devoid of echinoderms.

    - Crustaceans were most abundant along the upper portions of the OMZ, disappeared at depths of 800-1,000 m, and reappearing in small numbers as oxygen values increase. A group of hermit crabs was the only epifaunal organism observed in the core of the OMZ (~700 m), where oxygen concentrations drop below 0.3 ml/l O_2.
    - Though mollusks were at relatively low density in all depth zones, they were most abundant along the lower edge of the OMZ, with peak densities at ~1,100 m**.**

- **Benthic Fishes and Megafaunal Invertebrates West of Half Moon Bay (**SAIC and MLML 1992**)**. Results of cluster analysis based on density and histogram summaries based on species numbers, density, and biomass, indicated that benthic fish and megafaunal invertebrate communities are distributed primarily by depth, and are independent of study area boundaries. The mid-slope (500-1,200 m) community was characterized:
    - Fishes were common and included thornyheads, Dover sole, rattails, and finescale codling;
    - Megafaunal abundance was high and included Tanner crabs, sea stars, brittlestars, snails, and sea cucumbers.
- **Flatfishes on Smooth Ridge** (Vetter et al. 1994). Dover sole was the only flatfish at 600 m. Dover sole and deep-sea sole co-occurred at 800-1,200 m with both species common at the 1,000 m site.
- **Demersal Fishes off Point Sur** (Wakefield 1990). A study of the fish fauna for seven 200-m depth intervals from 400 to 1,600 m at Point Sur found that the upper slope habitat between 600 and 1,200 m contains a diverse array of fishes. Faunal break at 400-600 m, corresponds to a transition between shelf- and slope-dwelling species. The depth distribution of the adult population of a number of fishes (e.g., thornyheads, Dover sole, and sablefish) is centered within the OMZ. The following species were collected from at least one of the 3 stations in the OMZ (600, 800, 1,000 m): Pacific hagfish, sandpaper skate, bigfin eelpout, rex sole, filetail catshark, brown catshark, Dover sole, shortspine thornyhead, longspine thornyhead, sablefish, black hagfish, California slickhead, deep-sea sole, Pacific flatnose codling, giant grenadier, two-line eelpout, blacktail snailfish, snakehead eelpout, blackmouth eelpout, Pacific grenadier.
- **Groundfish Assemblage off U.S. West Coast Slope** (Tolimieri and Levin 2006). Data from trawl surveys along the U.S. west coast at 100 m intervals between 200-1,200 m revealed strong shift in fish assemblage structure at approximately 500-600 m and a second, more minor shift at 900-1,000 m. These shifts are likely due to temperature changes and possibly a response to the OMZ at 600-1,000 m. While temperature continues to decrease with depth, oxygen concentrations can increase below 1,000 m, which may explain the more minor shift in assemblage structure at around 900-1,000 m. Five assemblages were identified based on depth and latitude (Figure 18), two of which

intersect the OMZ:

  - **Shallow to mid-depth (200-1,000 m)/mid-latitude to southern assemblage:** sablefish, brown cat shark, aurora rockfish, Dover sole, and shortspine thornyhead*;*
  - **Deep (600-1,200 m)/broad latitude assemblage:** Pacific grenadier, giant grenadier, deepsea sole, longspine thornyhead, California slickhead, and roughtail skate.

- **Demersal Fishes on the Slope in the MBNMS** (Steve Ralston, pers. comm.). The depth distributions of 15 fish species/groups were determined using data from NWFSC slope trawl survey in the years 1999-2006 at sites in the MBNMS. Each species or genus generally fell into one of the following groups (Figure19):
  - **Common above OMZ (200-600 m):** chilipepper, shortbelly, stripetail, splitnose and aurora rockfishes, spotted ratfish, rex sole, and bigfin eelpout;
  - **Common above and inside OMZ (200-1,000 m**): cat sharks, Dover sole, sablefish, shortspine thornyhead
  - **Common inside and below OMZ (600->1,000 m):** longspine thornyhead, California slickhead, grenadier
- **Pelagic Invertebrates and Fishes** (Robison 2004, Gilly 2013): Larger animals that permanently inhabit the California OMZ include species with extremely low metabolic rates, like the slow-moving vampire squid (*Vampyroteuthis infernalis*) and mysid shrimp (*Gnathophausia ingens*), which have enhanced oxygen extraction and transport abilities. Other common inhabitants include bathylagid owlfishes, the pelagic worm *Poeobius meseres*, filter-feeding tunicates, and a diverse array of abundant cnidarians and ctenophores.
- **Epipelagic and Mesopelagic Organisms** (Bruce Robison, pers. comm.). The upper 1,000 m of the water column over the Monterey Canyon has been studied by Bruce Robison's lab at MBARI since 1992. Table 14 provides a preliminary evaluation of the relative frequency of sightings of the most commonly observed organisms in 100 m depth strata based on data collected between 2000-2002. This table shows the composition of mesopelagic organisms in Monterey Canyon at different depth strata in the OMZ, such as around the upper and lower boundaries.

Species Composition Shifts: Dissolved oxygen levels influence the distribution and abundance of species. Global climate change is expected to result in the expansion and intensification of the OMZ. Shifts in the location of the OMZ along central California could lead to shifts in the species composition at a given location. Additional processes that could result in shifts in species composition include food falls and periods of high productivity in surface waters, which deliver natural supplies of food to the slope. Humans activities that can influence species composition on the slope are discussed in "Shelf I & II – Hard Bottom", "Slope – Hard Bottom", and "Slope – Soft Bottom" habitat summaries.

- **Natural Changes:** Shifts in the location of the OMZ along central California could lead to shifts in species composition in the water column and the seafloor.

- **Shifts in Vertical Distribution of Pelagic Fauna** (reviewed in Gilly et al. 2013). The upper boundaries of OMZs have been shoaling (i.e., getting shallower) during the past 50 years. Shoaling of the OMZ upper boundary results in an expansion of hypoxic habitat for permanent OMZ dwellers, such as the vampire squid (*Vampyroteuthis infernalis*), the mysid shrimp (*Gnathophausia ingens*), and pelagic worm (*Poeobius meseres)*. However, shoaling of the OMZ upper boundary also results in a vertical compression of the pelagic habitat above the OMZ which may alter predator-prey interactions. Vast amounts of micronekton, particularly krill and myctophid fishes, take refuge from visually oriented predators near the upper boundary region of OMZs during daytime. A shoaling OMZ concentrates prey at shallower depths and may increase exposure of mesopelagic organisms to ambient light potentially increasing daytime foraging pressure by visually oriented predators. This effect may have been important in the recent range expansion of Humboldt squid in the California Current system. The potential expansion of the lower boundary of the OMZ would lead to an analogous shift to greater depths for those organisms that preferentially inhabit the lower boundary of an OMZ.
- **Benthic Macroinvertebrates**: Thompson et al. (1985) proposed the following zones relating oxygen concentrations with dominant benthic invertebrate fauna and sedimentary structures:
  - **anaerobic zone** (<0.1 ml/l O_2): devoid of macroinvertebrates and characterized by laminated sediments;
  - **dysaerobic zone** (0.1-0.3 ml/l O_2): dominated by small (1-2 mm), soft-bodied infauna that exhibits moderate disturbance of sediment due to bioturbation;
  - **aerobic zone** (> 0.1 ml/l O_2): inhabited by an abundant calcareous fauna and characterized by homogeneous, bioturbated sediments.

Species Diversity and Species Richness: A few studies in central California have examined species diversity or richness in the depth range of the OMZ. See “Slope – Hard Bottom” habitat summary for general information on this topic in the slope habitat.

- **Invertebrates Near Smooth Ridge** (CSLC & MBNMS 2005). 475 species of infaunal invertebrates were identified over the depth range 25-885 m. Polychaete worms showed the highest species richness at most depths. Gammarid amphipods were the most species rich group at 640 and 770 m stations. In addition, species richness was high for ophiuroids at the 450 m stations.
- **Infauna Near Davenport** (John Oliver, pers. comm.). In northern Monterey Bay and off Davenport, the mean number of species in sediment cores increased along the shelf, peaking at 109 and 150 m (at the shelf break), and then declined along the slope to 700 m. The mean number of species per sample was similar from 700-2,000 m. The number of species of crustaceans followed a similar pattern.
- **Megafaunal Invertebrates Inside and Outside Monterey Bay** (Oliver et al. 2011). Estimates of soft-bottom species density were obtained by sampling benthic megafaunal invertebrate communities in four major sampling programs along the coast of Central and

Northern California. Three of these programs were focused around the Monterey Bay area. Samples from 30 to 2,000 m depths were analyzed. Presence of the OMZ did not account for the lower species density on the slope compared to the shelf. The center of the OMZ harbored a dense community of ampeliscid amphipods, forming a tube mat that was seen in ROV video footage along four of the transects. Samples from the tube mat from the center of the OMZ at 700 m were included in the upper slope depth category (250-750 m), where there was relatively high species density (335 species/m^2). The lowest species densities (205 species/m^2) were found below the OMZ at 1000–2000 m.

- **Demersal Fish Species Richness** (Wakefield 1990). A study of the fish fauna on the slope at Point Sur found that the number of species identified from trawls was relatively constant at ~20 species for four 200-m depth intervals from 400 to 1,000 m, but decreased below 1,000 m.

Biomass: Detailed biomass studies have yet to be conducted for microbes, meiofauna, megafauna, or fishes within the OMZ in central California (Levin 2003). However, a few studies in central California have examined biomass in the depth range of the OMZ.

- **Invertebrates in the OMZ off central California** (Thompson et al. 1985). Correlation of biomass of major invertebrate groups from box core samples with dissolved oxygen content revealed a decrease in biomass below the 0.5 ml/1 O_2 level. Most major taxonomic groups were absent or represented by only a few species below the 0.3 ml/1 O_2 level. The highest invertebrate biomass was observed in the deeper portion of the OMZ (~800-900 m) and high biomass also was observed at the upper boundary of the OMZ (~500 m). These patterns were driven by echinoderms and polychaetes:
    - Echinoderms constituted over 90% (57 g/m^2) of the biomass within the OMZ, with highest density in the lower OMZ and moderate density near the upper and lower boundaries. Densities of up to 7/m^2 were observed for asteroids, up to 14/m^2 for irregular echinoids, and greater than 50/m^2 for ophiuroids
    - Polychaetes consistently dominate other groups in biomass due to their large numbers, but both the biomass and density of polychaetes decrease where echinoderms are abundant.
- **Groundfishes off Point Sur** (Wakefield 1990). A study of the fish fauna on the slope at Point Sur found that total fish biomass was relatively constant between 400-1,000 m (average of 24 mt/km^2), then decreased below 1,000 m to a minimum at 1,600 m (4 mt/km^2). Longspine thornyhead, was the dominant species in the OMZ; it was estimated that 93% of the spawning biomass of this species is found between 500 and 1,100 m. Other important taxa, either in terms of numbers or biomass, included black hagfish, shortspine thornyhead, Dover sole, Pacific grenadier, giant grenadier, sablefish, and eelpouts.
- **Thornyheads in central California** (Jacobson and Vetter 1996). Biomass for both thornyhead species off central California (Point Sur to Point Conception) is concentrated in the OMZ (600-1,000 m). The biomass of shortspine thornyhead was relatively constant across depth strata (400-1,000 m) whereas that of longspine thornyhead peaked sharply at 800–1000 m. Average biomass (kg/km^2) by depth stratum (m) were:
    - Shortspine thornyhead:

    - 200–400 m = 44 kg/km^2
    - 400–600 m = 714 kg/km^2
    - 600–800 m = 531 kg/km^2
    - 800–1000 m = 772 kg/km^2
    - 1000–1200 m = 176 kg/km^2
    - 1200–1400 m = 57 kg/km^2
  - Longspine thornyhead:
    - 200–400 m = 2 kg/km^2
    - 400–600 m = 692 kg/km^2
    - 600–800 m = 1,736 kg/km^2
    - 800–1000 m = 2,775 kg/km^2
    - 1000–1200 m = 216 kg/km^2
    - 1200–1400 m = 81 kg/km^2

MOVEMENT AND DISPERSAL

Almost all fishes exhibit some degree of ontogenetic shift in space utilization as they mature and the degree of movement or area used by adults may vary depending on species and location. This is particularly true of demersal species of fishes, such as flatfishes, some rockfishes, and wrasses (Lowe and Bray 2006). Most movement studies have been done on shallower water species. Ontogenetic migration (movement to deep water as fish grow and age) occurs in Dover sole and shortspine thornyhead.

- **Dover sole**. Both Hunter et al. (1990) and Vetter et al. (1994) found that Dover sole in central California showed a strong ontogenetic vertical migration through the OMZ. Juvenile Dover sole settle on the continental shelf and gradually move down the slope over their lifetime, reaching the OMZ as they become sexually mature. The average female Dover sole in central California reaches sexual maturity when about 7 years old and 31 cm long and occurs at a depth of about 329 m. At 16 years old, the average female lives at a depth of 640 m. At 27 years, the average female has descended to 1006 m. The greatest depth at which Dover sole was collected was 1269 m.

- **Shortspine thornyhead** (Point Sur to Point Conception; Jacobson and Vetter 1996). Size at depth analysis of thornyheads between 200-1,400 m indicate that shortspine thornyhead migrate ontogenetically by moving deeper with increasing size, although a few large fish were present at all depths. Small (<20 cm TL) shortspine thornyhead were seldom found at depths greater than 600 m. The mean size of shortspine thornyhead increased with depth and was greatest at 1000–1400 m.

Chemosynthetic Biological Communities

HABITAT OVERVIEW

When marine scientists first started studying a type of deep-sea community characterized by bacterial mats and certain species of chemosynthetic deep-sea clams and tubeworms, these areas were termed 'cold seeps communities'. However, after studying several hundred of these communities, Monterey Bay Aquarium Research Institute (MBARI) scientists found that many sites lacked signs of significant groundwater flow or seepage. Instead, these communities most often occurred in areas where previously buried sediments have been exposed by erosion. Such erosion may be caused by undersea landslides, or strong, persistent currents. For this reason, the phrase "chemosynthetic biological communities", or CBCs, is more general and encompasses all such communities including those at cold seeps (MBARI Press Room 2005).

CBCs have been observed primarily in slope, rise, and canyon habitats of the Monterey Bay (Figure 6; Charles Paull, pers. comm.). It is likely that CBCs occur in other portions of MBNMS, but very little exploration of deep-sea habitats has occurred outside the Monterey Bay area. CBCs in Monterey Bay have been found most frequently on steep slopes at depths exceeding 550 m at sites where recent erosion has uncovered sediments rich in reduced chemical compounds such as hydrogen sulfide and methane (Paull et al. 2005a). Based on Carbon-14 dating, CBCs could persist for centuries after the initial slide and some animals can live for many decades (Paull et al. 2005b).

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	No specific information was found on this topic. However, it is likely that the biogenic structure formed by chemosynthetic clams and tubeworms serves as nursery habitat for the juvenile phase of some mobile species such as crabs and fish.
Feeding Ground:	No specific information was found on this topic. However, mobile, demersal fish and invertebrates (e.g., crabs, octopus, snails) have been observed at CBCs. These species may be attracted to CBCs to forage on the large, sedentary clams that are characteristic of CBCs or on other prey species that are in high densities around CBCs.
Spawning Ground:	No specific information was found on this topic.
Migratory Corridor:	See page 133
Biogenic Habitat:	See page 133
Energy Flow:	
Primary Production:	See page 133

Benthic-Pelagic Coupling:	See page 134
Key Trophic Interactions:	See page 134
Key Trophic Cascades:	No specific Information found on this topic
Productivity Hotspots:	Chemosynthesis supports the much higher species richness and biomass found at CBCs compared to surrounding soft sediment habitats in the deep sea
HABITAT STRUCTURE	
Species Composition:	See page 134
Species Composition Shifts:	See page 135
Species Diversity and Richness:	Chemosynthesis supports the much higher species richness (>70 species) of megafauna found at CBCs compared to surrounding soft sediment habitats in the deep sea (Barry et al. 1996)
Biomass:	Chemosynthesis supports the higher biomass found at CBCs compared to surrounding soft sediment habitats in the deep sea.
Key Species Interactions	See page 136
MOVEMENT AND DISPERSAL	See page 136
SPECIES OF SPECIAL INTEREST	No landed, endangered and threatened or at-risk species have been observed at CBCs (Table 21). The structure-forming invertebrates that are common at CBCs are of special management interest due to their important ecological role in creating habitat structure and their vulnerability to disturbance from human activities.

HABITAT SUMMARY

HABITAT FUNCTION

Functional Habitats

Migratory Corridor: Some of the species observed at CBCs are obligate species that are found only at CBCs or other chemosynthetic habitats (e.g., hydrothermal vents, large animal falls). Obligate species probably use these spatially distinct habitats as stepping-stones for dispersal (Smith et al. 1989). Dispersal may occur during the larval stage (sessile and mobile species) or at older life stages (mobile species only).

Biogenic Habitat: Most of the chemosynthetic organisms found at CBCs, such as vesicomyid clams and vestimentiferan worms, are large, sedentary organisms. Sessile organisms use these structure-forming invertebrates as a hard substrate for attachment and by some mobile organisms as shelter or food.

Energy Flow

Primary Production: The only form of primary production in deep-sea habitats is chemosynthesis. Chemosynthetic bacteria, located in mats or living as symbionts in the tissues of larger organisms, use energy stored in certain chemical compounds (e.g., hydrogen sulfide and methane) to convert water and carbon dioxide into organic carbon (food). The organic carbon fixed by chemosynthetic organisms forms the base of the food web in CBCs.

Benthic-Pelagic Coupling: The flux of material between the benthos and the overlying water column occurs through sinking of non-living organic matter and the active movement of organisms. Falling plankton, fecal pellets, animal carcasses, and drift algae serve as subsidies that may be scavenged by detritivores within the CBC. CBCs (along with hydrothermal vents) are some of the only habitats in the deep sea where falling organic matter is not the primary source of organic carbon for the food web. See Appendix III for more general information about benthic-pelagic coupling.

Key Trophic Interactions:

- **Chemosynthesis** supports either directly or indirectly a large portion of the species found in association with CBCs. Species can be classified into three groups depending on their level of dependence on chemosynthetic energy:
    - **Obligate species:** These species are only found at CBCs. These species are either chemoautotrophic bacteria or serve as hosts to chemoautotrophic bacterial symbionts.
    - **Potentially obligate species:** These species are only found at CBCs and may harbor chemoautotrophic symbionts or feed almost exclusively on chemosynthetic organisms.
    - **Non-obligate (or regional species):** These species occur at CBCs, but also occur at non-seep habitats in the region. These species are not chemoautotrophic and, though they may feed on chemosynthetic organisms, their diet is not restricted to such organisms.
- **Predation** (summarized in Airamé et al. 2003). Lithodid and brachyuran crabs have been observed to prey on vesicomyid clams. Tanner crabs (*Chionoecetes tanneri*) prey on vesicomyid clams in the laboratory and are likely to consume clams in the field. Buccinid snails (*Neptunea amianta*) scavenge dead vesicomyid clams at cold seeps in Monterey Bay. Holes in vesicomyid shells provide further evidence of predation by snails or octopus. Surficial grazing of the shell by columbellid gastropods may benefit vesicomyid clams by removing bacterial films from the clams' shells.

HABITAT STRUCTURE

Species Composition:

- **Cold Seeps in Monterey Bay** (Barry et al. 1996). Four cold seeps in the Monterey Bay region (600-1000 m) were surveyed. Individual seeps were small, rare, highly localized communities. Table 21 provides a complete list of taxa found at these four sites. The species were placed into three groups based on their dependence on cold seeps:
    - **Obligate species:** At least 9 taxa, including vesicomyid clams, solomyid clams, tubeworms, and bacterial mats, are either chemoautotrophic or harbor chemoautotrophic symbionts. Vesicomyid clams tend to be the numerically dominant obligate species at cold seeps in the Monterey Bay area;

  - **Potentially obligate species:** At least 3 taxa, a columbellid gastropod, a pyropeltid limpet, and an unknown galatheid crab, may harbor chemoautotrophic symbionts or feed almost exclusively on chemosynthetic organisms;
  - **Non-obligate or Regional species:** At least 55 taxa, including deep-sea coral, anemones, snails, segmented worms, crabs, brachiopods, crinoids, sea stars, brittle stars, sea urchins, sea cucumbers, hagfish, catsharks, thornyheads, and flatfish, occur at seeps and at non-seep habitats in the region.
- **Relative Abundance of Clams at Cold Seeps in Monterey Bay** (Barry et al. 1997). The distributions of vesicomyid clams species correspond closely to patterns of sulfide and methane concentrations in the sediments. The vesicomyid clam, *Phreagena kilmeri*, accounted for 85-99% of all vesicomyids at seeps with high sulfide concentrations. In contrast, *C. pacifica* dominated (73%) seeps with low sulfide levels. These species were also partially segregated along sulfide gradients from the center to the margin of seeps, analogous to zonation in rocky intertidal communities.
- **Clams at Cold Seeps along the US West Coast** (Goffredi et al. 2003). Vesicomyid clams are one of the dominant invertebrates at chemosynthesis-based communities (deep-sea cold seeps and hydrothermal vents). Three vesicomyid clam species that co-occur in the Monterey Bay appear to be spatially segregated by depth:
  - *Vesicomya pacifica* (type I clam): 500-1000 m;
  - *Vesicomya* spp. (type II clam): depth range 1550-2200 m;
  - *Vesicomya* spp. (type III clam): depth range 2200-2500 m.

Species Composition Shifts:

- **Natural Changes:** CBCs differ substantially in species composition compared to the surrounding soft bottom habitat. Erosion that uncovers sediments with sufficient levels of reducing compounds to support a CBC is a natural cause of species compositions shifts in the deep sea. As the availability of reducing compounds in the sediments changes, the species composition at the CBC changes. Once the concentration of reducing compounds drops too low in a given area, obligate species can no longer produce enough food to support the community and the CBC will eventually disappear.
  - **Succession at CBCs in Monterey Bay** (Paull et al. 2005b). The chemosynthetic organisms observed on slide scars in Monterey Canyon undergo a faunal succession based in part on their lifecycle and their ability to maintain access to hydrogen sulfide in the sediments. Various chemosynthetic taxa are capable of exploiting reduced chemical compounds at different depths below the seafloor.
    - Bacterial mats may form and die off on timescales of weeks. Bacterial mats occur where both oxygen and hydrogen sulfide are in close (~1 cm) proximity to the seafloor.
    - Vesicomyid clams live for years to perhaps a century. Some vesicomyid clam species can span distances of 20 cm or more, by the distension of their muscular foot into sulfidic sediments, while maintaining contact with oxygenated seawater through their ventilation siphons at their opposite end.

- Vestimentiferans may live over 250 years, and are known to survive on very low supplies of hydrogen sulfide. Vestimentiferan tubeworms have ‘‘roots’’ that may extend over 2 m into the seafloor to obtain hydrogen sulfide, whereas their anterior end is exposed to oxygenated seawater.

The timing of community succession will depend on how quickly the chemical compounds retreat from near the surface. As the hydrogen sulfide-bearing horizons retreat into the subsurface, the exposed bacterial mats would cease to be viable, and the vesicomyids would be compelled to bore into the mudstone to follow receding hydrogen sulfide-bearing zones. Once access to hydrogen sulfide is terminated, vesicomyid clams would die, shifting to a later successional phase dominated by vestimentiferan worms.

- **Human-induced Changes:** CBCs, like all benthic biogenic habitats, are susceptible to degradation from human activities that disturb benthic habitats such as fishing with bottom-tending gear, laying physical structures (e.g., cables), dredging and waste disposal. Removal of or damage to chemosynthetic sessile invertebrates has the potential to temporarily or permanently alter species compositions at these sites.

Key Species Interactions: Little or no information is available concerning ecological processes that influence demographic rates of biological populations at CBCs. Predation, competition, and disturbance likely play a major role, but few hypotheses regarding these population processes have been addressed (Barry 1996).

- Mutualism: Vesicomyid clams, solomyid clams, and tubeworms support chemoautotrophic bacteria in a symbiotic relationship. The bacteria use energy from the inorganic chemical compounds present in the sediments to make organic compounds. The clams and worms use the organic compounds produced by the bacteria as food.

MOVEMENT AND DISPERSAL

Some species that occur at CBCs, such as chemosynthetic bacteria and clams, are also found at whale falls and hydrothermal vents (Smith et al. 1989, Smith and Baco 2003). CBC-associated organisms may use whale carcasses and vents as stepping-stones during dispersal between CBCs.

- Goffredi et al. (2003) found that three closely related species of vesicomyid clams were genetically differentiated by depth, but not by region or geographic proximity. The authors suggest that the presumed continuous free spawning and high fecundity of vesicomyids allow dispersal over the distances separating populations (generally <50 km).

Macrophyte Detritus

HABITAT OVERVIEW

Macrophytes, including large kelps, smaller algae, and seagrasses, are major primary producers in the marine environment, but only grow in relatively shallow nearshore habitats. Periodically large storms and other disturbances cause parts of the macrophytes to break loose. This material, which can be exported as floating rafts or as benthic deposits, then becomes a source of food and shelter in other marine habitats such as offshore surface waters and benthic habitats on the shelf, slope, and in submarine canyons.

Floating mats of kelp provide rare physical structure in open water and tend to attract mobile fishes and invertebrates. Macrophyte drift that settles to the benthos provides physical structure to benthic communities and food for detritivores. Though macrophyte detritus can be found in any benthic habitat, studies in central and southern California have demonstrated that it is more abundant in submarine canyons than on the adjacent shelf and slope. Macrophyte detritus drifting along the coast in currents accumulates in canyon heads, especially in submarine canyons that extend into nearshore waters. Periodic sediment flows then move this material into deeper portions of the canyons.

SEARCH TOPIC TABLE

HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	Juveniles of a number of sport and commercial fishes are found in association with floating kelp mats, including jacks, sablefish, rockfishes, and yellowtail (Rigsby 1999a, Allen and Cross 2006).
Feeding Ground:	See page 138
Spawning Ground:	No specific information was found on this topic.
Migratory Corridor:	No specific information was found on this topic.
Biogenic Habitat:	See page 139
Energy Flow:	
Primary Production:	Harrold et al. (1998) estimated that the kelp forests lining the southern tip of Monterey Bay generate >$2x10^5$ metric tons (wet weight) of macrophyte drift each year.
Benthic-Pelagic Coupling:	See page 139
Key Trophic Interactions:	No specific information was found on this topic.
Key Trophic Cascades:	No specific information was found on this topic.

Productivity Hotspots:	Macrophyte detritus is a hotspot of productivity in many benthic habitats, especially in deeper water habitats where primary production does not occur (with the exception of chemosynthetic biological communities) and the supply of organic carbon is limited. Submarine canyons, especially those extending into nearshore waters, appear to be areas with unusually large concentrations of macrophyte detritus and, thus, hotspots of organic enrichment.
HABITAT STRUCTURE	
Species Composition:	See page 140
Species Composition Shifts:	See page 141
Species Diversity and Richness:	See page 141
Biomass:	See page 141
Key Species Interactions	No specific information was found on this topic.
MOVEMENT AND DISPERSAL	No specific information was found on this topic.
SPECIES OF SPECIAL INTEREST	Some invertebrate and fish species of special interest have been observed to associate with macrophyte detritus. Examples include sea cucumbers, sea stars, octopus, hake, thornyheads, sablefish, and Dover sole. In addition, the juveniles of some fishes landed in MBNMS, such as jacks, sablefish, rockfish and yellowtail, associate with floating kelp mats in the open ocean.

HABITAT SUMMARY

<u>HABITAT FUNCTION</u>

Functional Habitats

Nursery Habitat:

Feeding Ground: Macrophyte detritus is a very concentrated source of organic matter. Exported macrophyte detritus may represent a significant source of nutrition for resident benthic organisms in habitats in close proximity to areas of high macrophyte density (e.g., kelp beds, seagrass beds). Macrophyte detritus is probably a particularly important food subsidy in deep-sea environments where food availability tends to be limited. Nearshore submarine canyon heads accumulate drift macrophytes and channel them to deeper waters.

- **Carmel Canyon** (Harrold et al. 1998). The stomachs of the sea urchin *Strongylocentrotus fragili* collected from the canyon were packed with algal material, while the stomachs of sea urchins at Point Joe (the adjacent shelf and slope site) had much lower algal content and lower gut fullness. In addition, gonad indices of *S. fragilis* from Point Joe were lower than those from the Carmel Canyon suggesting that Point Joe sea urchins were in a poorer nutritional state. Drift algae appears to provide a predictable source of nutrition for sea urchins in the canyon allowing for a higher reproductive condition compared to urchins on the adjacent shelf and slope at Point Joe.

- **Southern California** (Vetter and Dayton 1998, 1999). In Scripps and La Jolla Canyons, macrophyte detritus is a source of food for many different species of invertebrates, such as amphipods, crustaceans, sea cucumbers, and sea urchins.

Biogenic Habitat: Macrophyte drift is a source of physical structure for shelter and food (or both) for a number of species.

- **Floating Kelp Mats.** Ocean-going mats of kelp provide shelter to many species that otherwise find little shelter in the open ocean, including juvenile sea turtles, swimming crabs, and the young of important sport and commercial fishes such as jacks, sablefish, rockfishes, and yellowtail (Rigsby 1999a, Allen and Cross 2006).
- **Macrophyte Detritus** in the axis of La Jolla and Scripps Canyon appeared to be utilized as food and shelter by some species of fish and invertebrates, including the crab *Glyptolithodes cristatipes*, the eelpout *Eucryphycus californica*, and, at depths between 300-500 m, patches of drift surfgrass (*Phyllospadix* spp.) were frequently observed with large aggregations of amphipods (Vetter and Dayton 1999). Examples of associations with other structures in the canyon axis included: a small tree branch found at 700 m was inhabited by large numbers of snails and amphipods. A small log found at 500 m hosted large crabs (*G. cristatipes*). In the Monterey Canyon, the persimmon eelpout (*Maynea californica*) was commonly associated with macroalgae drifting on the bottom of the canyon at depths of 70-550 m (Cailliet and Lea 1977 cited in Airamé et al. 2003).

Energy Flow

Benthic-Pelagic Coupling: There is a two-way exchange, or flux of matter, between the benthos and the overlying water body, which is important for both benthic and pelagic compartments. This flux occurs through the passive movement of non-living organic matter and the active movement of organisms. Macrophytes exported from kelp beds and seagrass beds tend to float initially (upward flux of primary productivity into the pelagic compartment), but eventually settle to the seafloor (downward flux of organic matter to the benthic compartment). See "Appendix III– Benthic Pelagic Coupling" for a general overview.

- **Monterey Canyon**. Macrophyte detritus accumulates in the head of Monterey Canyon throughout the year, but the type and amount of algae varies according to season. Late spring and summer are times of accumulation and burial. In fall and winters, episodic flushing events deliver the algal detritus down the canyon axis (Okey 2003). Goffredi et al. (2004) observed relatively fresh surfgrass debris near a whale fall in the Monterey Canyon during all three observation periods. The density of marine debris near the whale fall site supported the idea of frequent and intense flow events, resulting in the accumulation of materials within the canyon axes.
- **Carmel Canyon**. Harrold et al. (1998) surveyed three sites [Carmel Canyon shallow (153-378 m); Carmel Canyon deep (288-454 m); adjacent shelf at Point Joe (87-357 m)] to examine the organic enrichment of submarine-canyon and continental shelf benthic communities by macrophyte drift. They found that macrophyte drift deposits were more frequently observed in submarine canyon habitats than on the adjacent shelf and slope habitats. At both shallow and deep canyon sites, deposits were more frequently observed at the base of canyon walls than in the middle of the canyon floor. The daily flux of organic carbon derived from the giant kelp (*Macrocystis pyrifera*) to the canyon study

sites was estimated to be 45.2 mg C/ m^2/ day (this is a rough approximation based on many assumptions). Compared to estimates of carbon flux from vertically sinking particulate organic carbon (POC) at 400-m depth in the nearby Monterey Canyon, drift *M. pyrifera* can account for 20-83% of the total POC reaching the seafloor in the Carmel Canyon.

- **La Jolla and Scripps Canyon** (Vetter and Dayton 1998, 1999). Longshore transport delivers substantial quantities of macrophyte detritus from surfgrass (*Phyllospadix torreyi*), kelps (*M. pyrifera* and *Egregia menziesii*), and other macroalgae to the heads of Scripps and La Jolla Canyons. Strong tidal and gravity currents distribute this material throughout much of the canyon system.
- **Davidson Seamount** (Burton and Lundsten 2008). Drift algae and surfgrass have been observed on the Davidson Seamount, including *Alaria marginata*, *Macrocystis* sp., *Nereocystis luetkeana*, and *Phyllospadix* spp.

HABITAT STRUCTURE

Species Composition: A variety of plants and algae including, seagrasses, green algae, red algae, and brown algae, compose the macrophyte detritus observed in central and southern California. However, drift from large kelps (a type of brown algae) tends to be observed most often. A variety of fishes and invertebrates are commonly found in association with macroalgal detritus.

- **Carmel Canyon** (Harrold et al. 1998). The macrophyte drift commonly observed in Carmel Canyon over a 3-year study was composed of a diverse assemblage of algal species. Red and brown algae were most common, especially *M. pyrifera*. Surfgrass, *Phyllospadix* spp., was ubiquitous through all areas surveyed, but at low biomass (it occurred mostly as widely scattered single strands).
- **Monterey Canyon** (Okey 2003). Amphipods dominated natural patches of sunken algae in Monterey Canyon's shallow head during winter and spring, while polychaete worms dominated during late summer and fall. In addition, comparative sampling revealed substantial differences in the invertebrate communities associated with patches of macrophyte detritus and background sediment.
- The persimmon eelpout (*Eucryphycus californicus*) is commonly associated with macroalgae that drift on the bottom of Monterey Canyon to depths of 70-550 m (Cailliet and Lea 1977 cited in Airamé et al. 2003).
- **La Jolla and Scripps Canyon** (Vetter and Dayton 1998, 1999). The floor of Scripps Canyon from 15 m to >60 m is often covered with a persistent mat of kelp (*M. pyrifera* and *Egregia menziesii*) and seagrass (*Phyllospadix* spp. and *Zostera marina*) detritus. The following species were associated with macrophyte detritus in La Jolla and Scripps Canyons between 100-500 m: amphipods (many species), polychaete worms (many species), heart urchins (*Brissopsis pacifica*), sea urchins (*S. fragilis* and *Lytechinus pictus*), sea stars, sea cucumbers (*Pannychia moseleyi* and *Parastichopus* spp.), benthic siphonophores (*Dromalia alexandri*), decapods (including the crab *Glyptolithodes cristatipes*), octopus, juvenile and adult hake, thornyheads, sablefish, witch eel, Dover sole, turbot (*Pleuronichthys* spp.), eel pouts *(Lycodes pacifica* and *E. californica*), and scorpionfish (*Scorpaena guttata*).

Species Composition Shifts:

- **Natural Changes:** Mobile invertebrates and a few species of fish rapidly colonize mats of macrophyte detritus. Comparative studies (Okey 2003, Vetter and Dayton 1998, 1999) have found substantial benthic community differences between algal patches and background sediment. In addition, Okey (2003) found that the invertebrate assemblage on patches of macrophyte detritus shifted between an amphipod-dominated assemblage in the spring to a polychaete-dominated assemblage in the fall. This shift in species assemblage was related to both dissolved oxygen and level of disturbance (time since flushing events). Crustaceans, with their highly mobile adult phase, were able to rapidly colonize ephemeral patches of sunken drift algae and rapidly recover after disturbance, but were sensitive to hypoxia. The more sedentary polychaete worms were slower to colonization patches of algal detritus and were more sensitive to physical disturbance, but had a higher tolerance to hypoxia.

Species Diversity and Species Richness:

- **Macrofauna associated with drift in Monterey Canyon** (Okey 2003). Species richness was highest when both crustacean and polychaete groups inhabited detrital patches. The two species groups tended to co-occur at intermediate levels of disturbance and dissolved oxygen.

Biomass:

- **Macrophyte Drift in Carmel Canyon** (Harrold et al. 1998). The volume of deposits of macrophyte detritus was generally <0.5 m^3, but some massive deposits (up to 7 m^3) were observed. The carbon biomass of drift *M. pyrifera* observed in this study spanned four orders of magnitude. The lowest biomass (~1-10 mg C/m^2) was consistently observed on the shelf and slope at Point Joe while much higher biomass (~100-10,000 mg C/m^2) was observed in Carmel Canyon. Shallow canyon sites tended to have higher biomass than deep canyon sites. The lower biomass of drift algae at Point Joe was probably due to lower flux and higher consumption by resident herbivores at higher density (density of the sea urchin *A. fragilis* was always at least an order of magnitude higher at Point Joe).

- **Macrophyte Drift in Southern California** (Vetter and Dayton 1998, 1999). Mats of macrophyte detritus in Scripps and La Jolla Canyons were commonly 7-15 m thick and ranged in size from <1 to >30 m^2 in area. Macrophyte detrital cover on the canyon floor decreased with depth: 100% at 65 m, 11-13% at 280-300 m, and 5% at 500 m in Scripps Canyon; 13% at 300 m and 5% at 500 m in La Jolla Canyon.

- **Macrofauna associated with drift in Monterey Canyon** (Okey 2003). Up to 5.7×10^5 individual macrofauna/m^2 inhabited naturally occurring patches of sunken drift algae in Monterey Canyon's shallow head.

- **Fauna associated with drift in Southern California** (Vetter and Dayton 1998, 1999). In the axis of La Jolla and Scripps Canyon, megafaunal abundance was higher near macrophyte detritus. Algal detritus can support very high densities of amphipod and crustacean densities (at times >3 million individuals/m^2) with biomass exceeding 1 kg/m^2.

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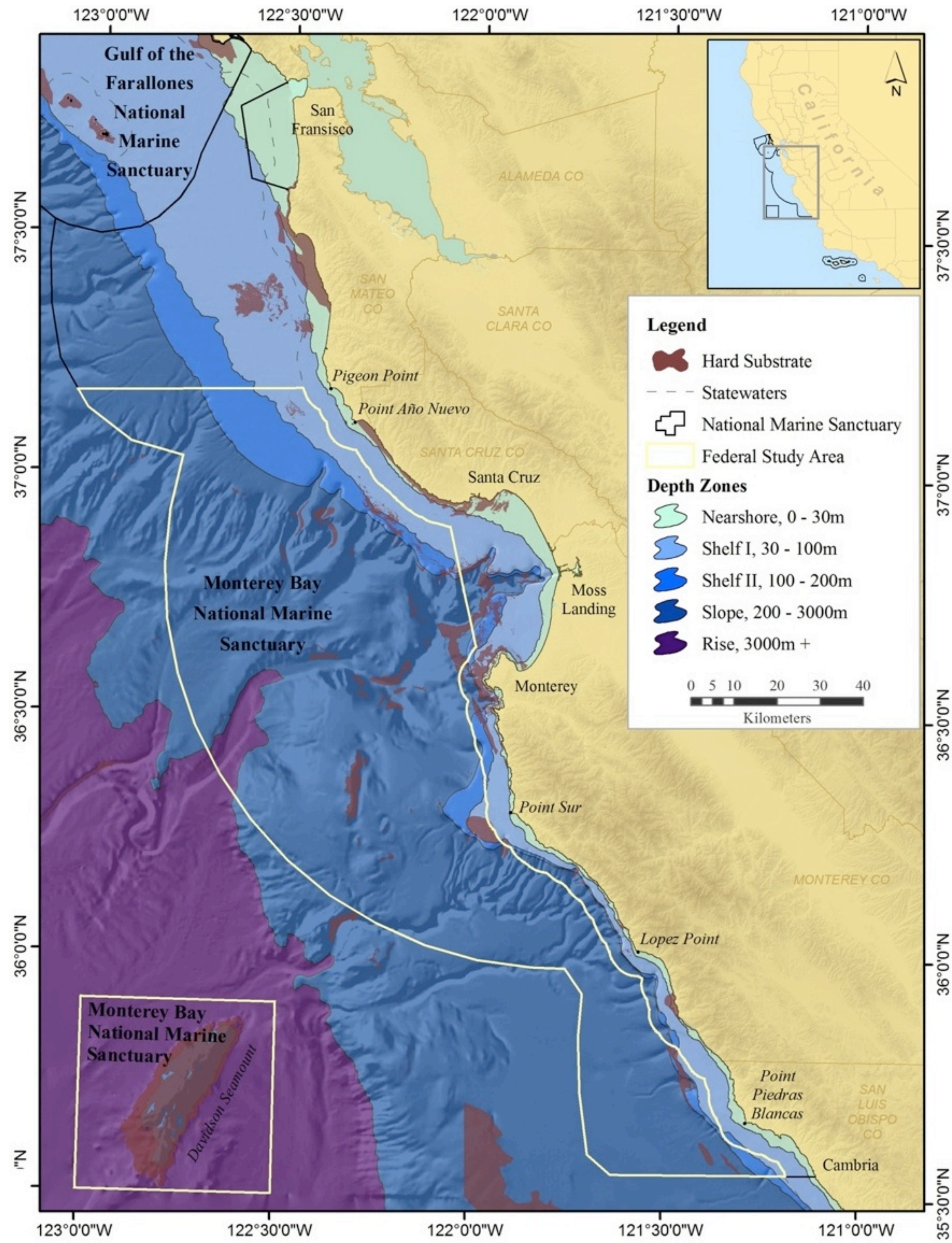

Figure 1. Benthic habitat categories in Monterey Bay National Marine Sanctuary.
Hard substrate (shown in brown) is likely to be under-represented, especially smaller patches, because high-resolution substrate data are not available for the entire offshore environment. Data Credit: Moss Landing Marine Laboratories and TerraLogic GIS, Inc.

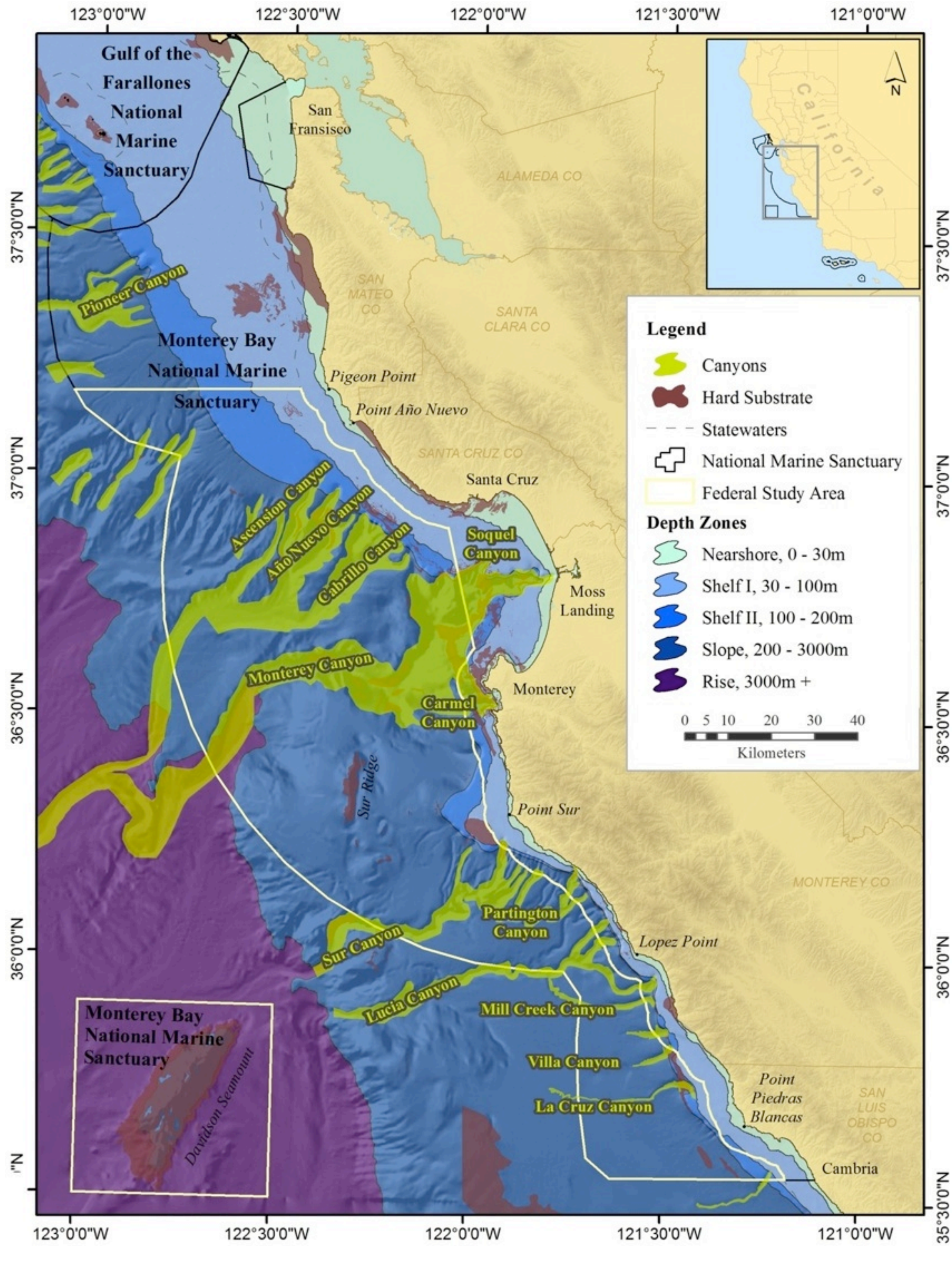

Figure 2. Submarine canyons in Monterey Bay National Marine Sanctuary.
The yellow outlines include both the central channel and sloping walls of submarine canyons. This data layer was developed by the National Center for Coastal Ocean Science (NCCOS) using California Department of Fish and Game multibeam bathymetry, depth variance and 50 m contours, an existing GIS dataset developed by Greene et al. (1999) and NCCOS's physiographic features layer. In cases where two or more canyon features were in close proximity and clearly part of the same geological feature, they were united.

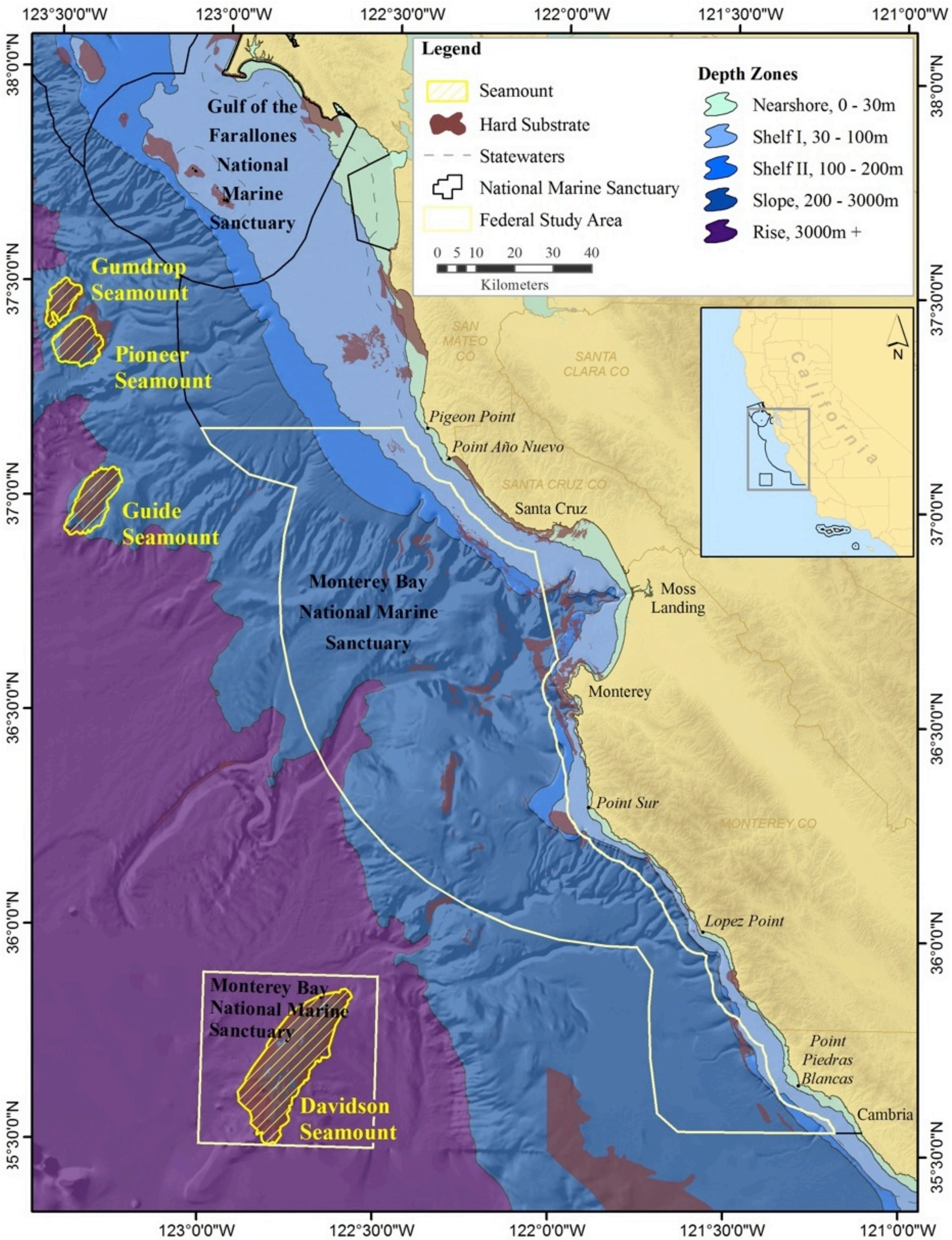

Figure 3. Seamounts in and adjacent to Monterey Bay National Marine Sanctuary.
The seamount data was developed by the NOAA's National Center for Coastal Ocean Science (NCCOS) in 2007.

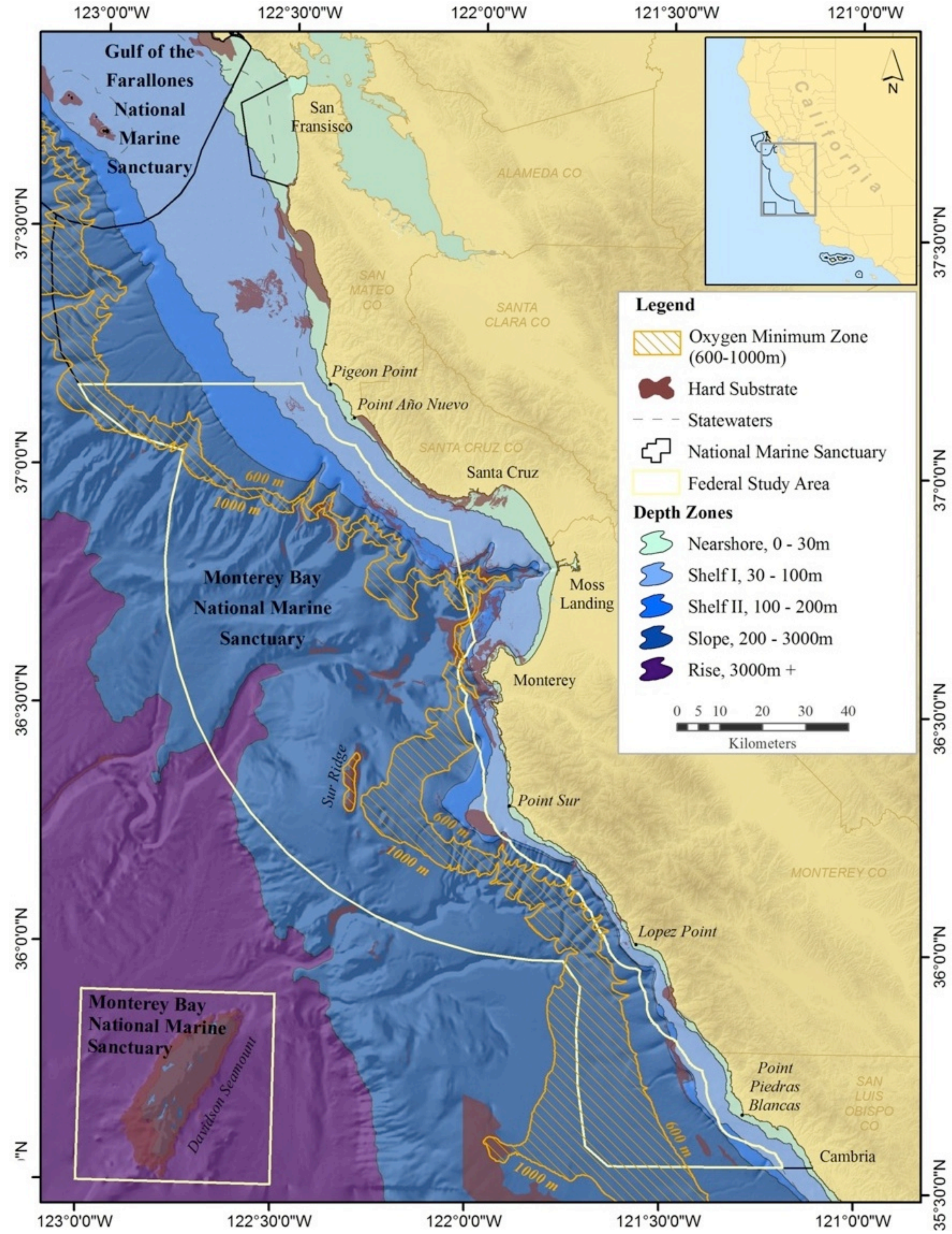

Figure 4. Oxygen Minimum Zone in Monterey Bay National Marine Sanctuary.
The oxygen minimum zone (orange hatching), a portion of the water column with reduced levels of dissolved oxygen, intersects the seafloor in the slope benthic habitat category. Upper (600 m) and lower (1,000 m) boundaries are based on estimates from studies in central California.

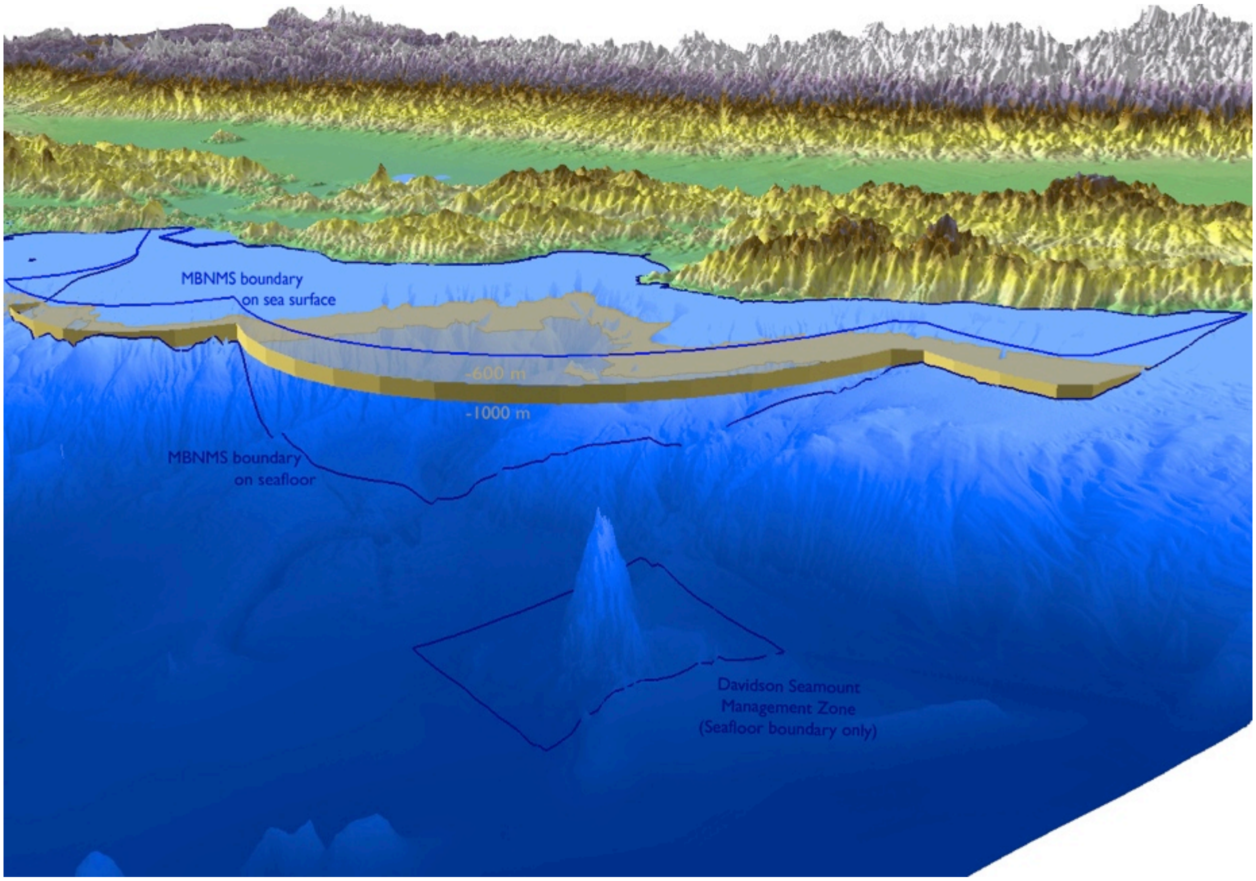

Figure 5. Three dimensional view of the Oxygen Minimum Zone in MBNMS.
This view helps illustrate that the oxygen minimum zone (gold shading) is a 400 m zone that occurs along the seafloor on the landward side of the zone and is a mid-water column feature in deeper portions of the sanctuary. Upper (600 m) and lower (1,000 m) boundaries of the oxygen minimum zone are based on estimates from studies in central California.

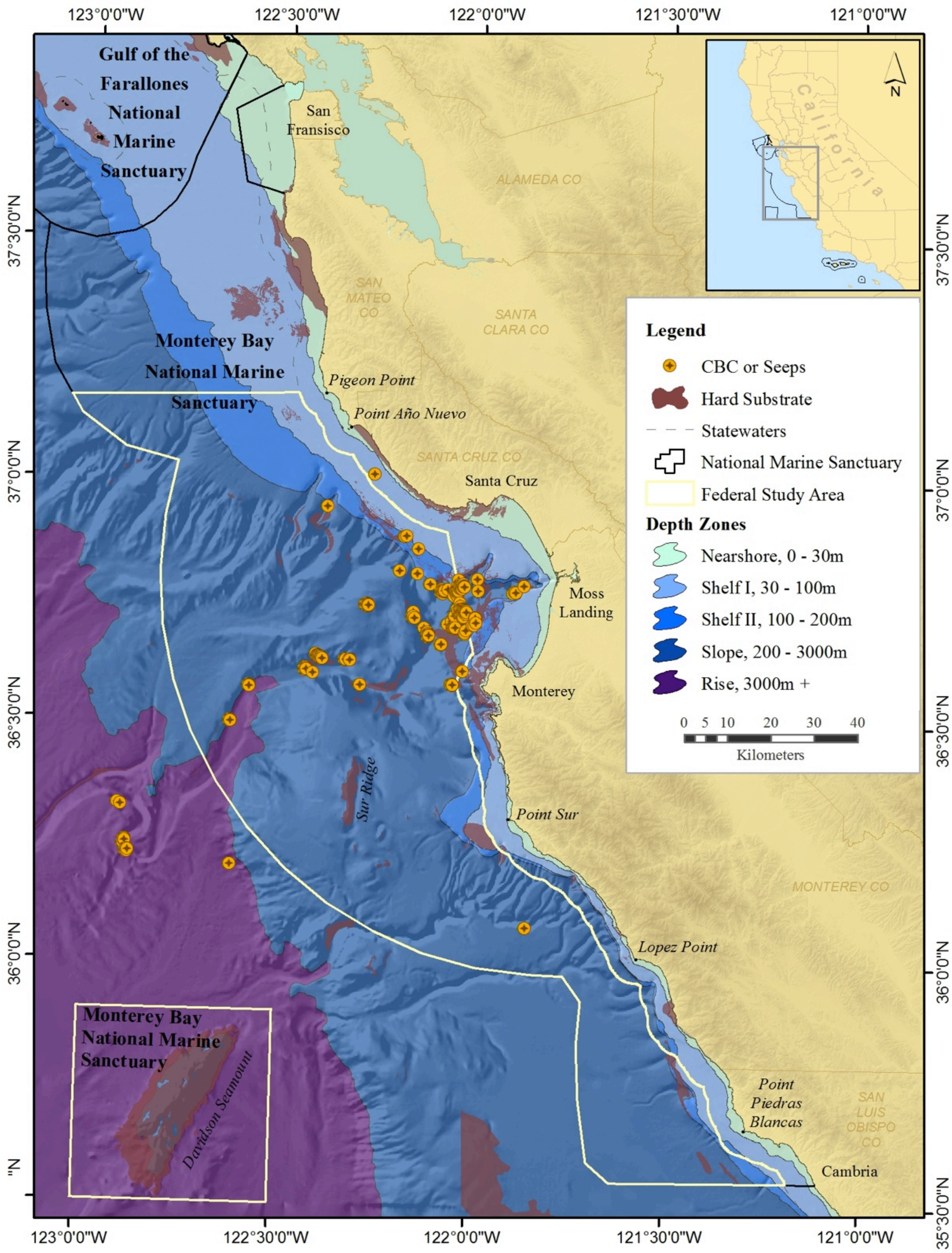

Figure 6. Observations of Chemosynthetic Biological Communities in MBNMS.
Locations where Chemosynthetic Biological Communities (CBC) or seeps have been observed during Monterey Bay Aquarium Research Institute (MBARI) ROV surveys 1989-2009. Locations were obtained through a query of MBARI's public Video Annotation and Reference System (VARS) for seeps and Vesicomyidae and taxonomic descendents. This map does not indicate survey effort. It is likely that CBCs occur in other portions of the sanctuary, but very little exploration of deep-sea habitats has occurred outside the Monterey Bay region. Data credit: Monterey Bay Aquarium Research Institute

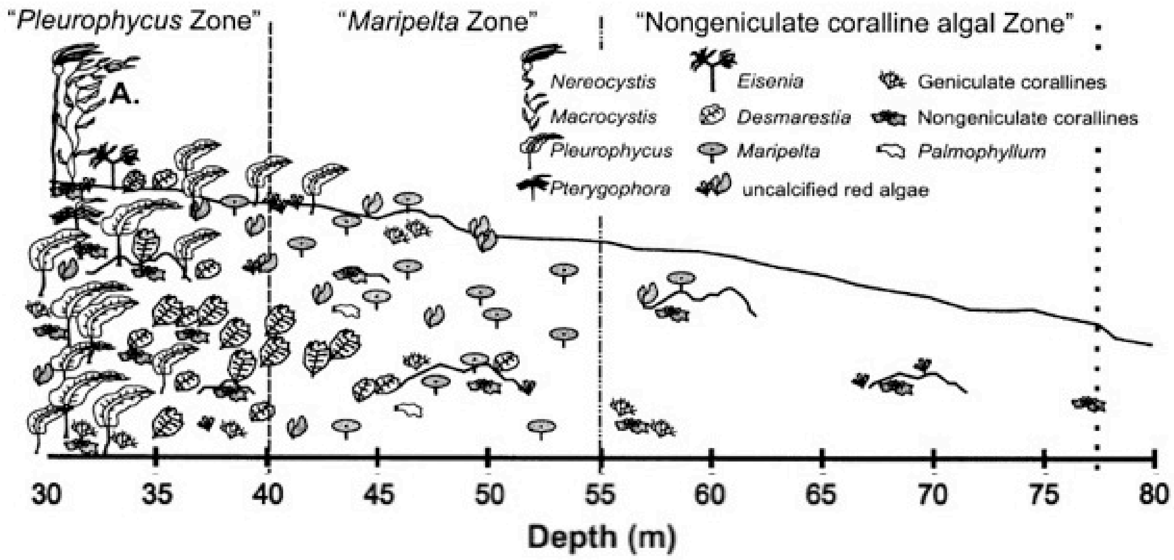

Figure 7. Depth distribution and relative abundance of deep-water algae along the central California coast. Spalding et al. (2003) found that algae in waters deeper than 30 m were distributed in three broadly overlapping zones characterized by one or a few visually dominant taxa (reprinted with permission).

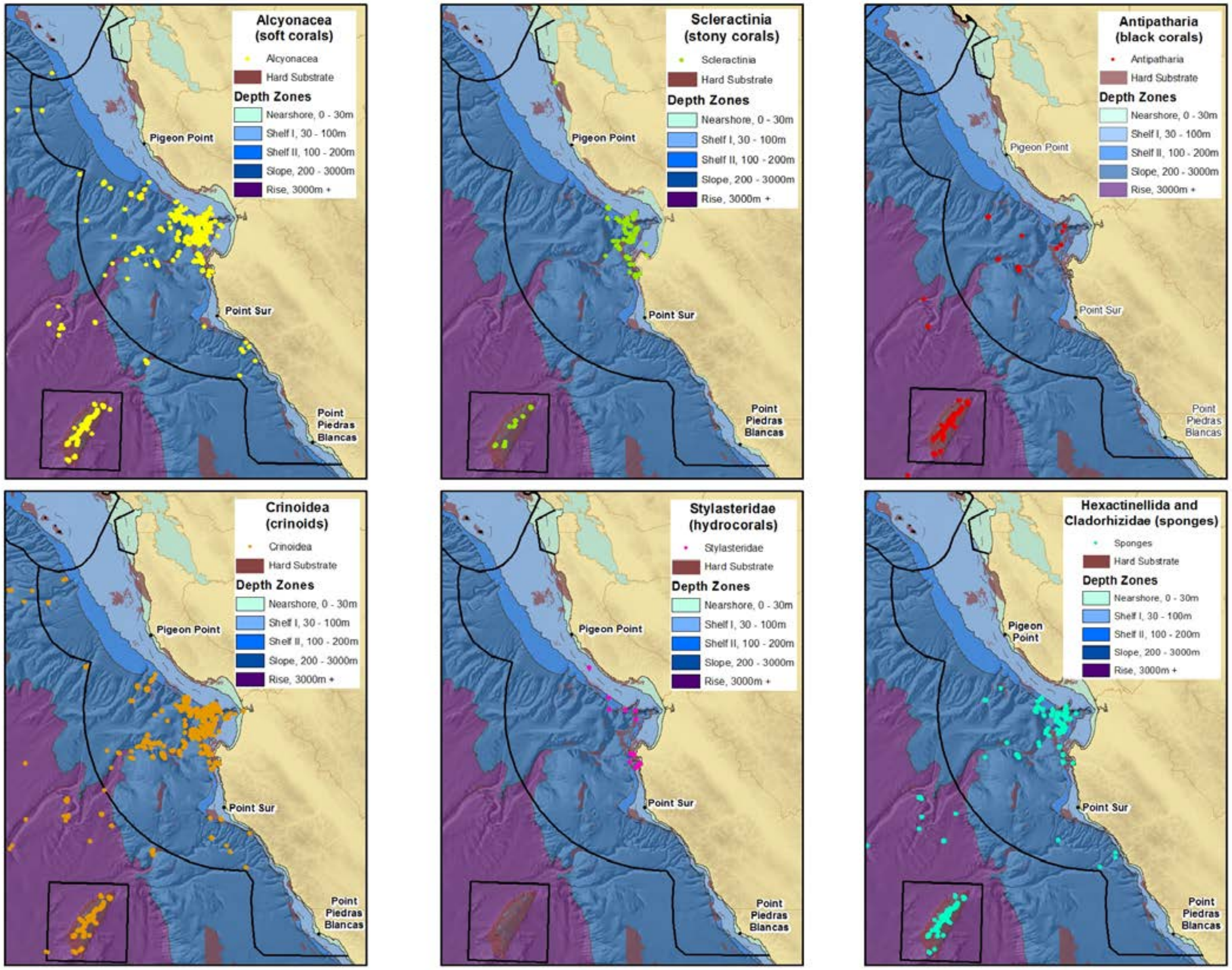

Figure 8. Observations of structure-forming invertebrates associated with hard substrate.
Locations where structure-forming invertebrates associated with hard substrates (soft, stony, and black corals, crinoids, hydrocorals and sponges) have been observed during Monterey Bay Aquarium Research Institute (MBARI) ROV surveys 1989-2009. Each data point represents a sighting regardless of the abundance of the organisms in the video frame. These organisms also occur in areas that have not been sampled by MBARI (survey effort not show). Data credit: Monterey Bay Aquarium Research Institute

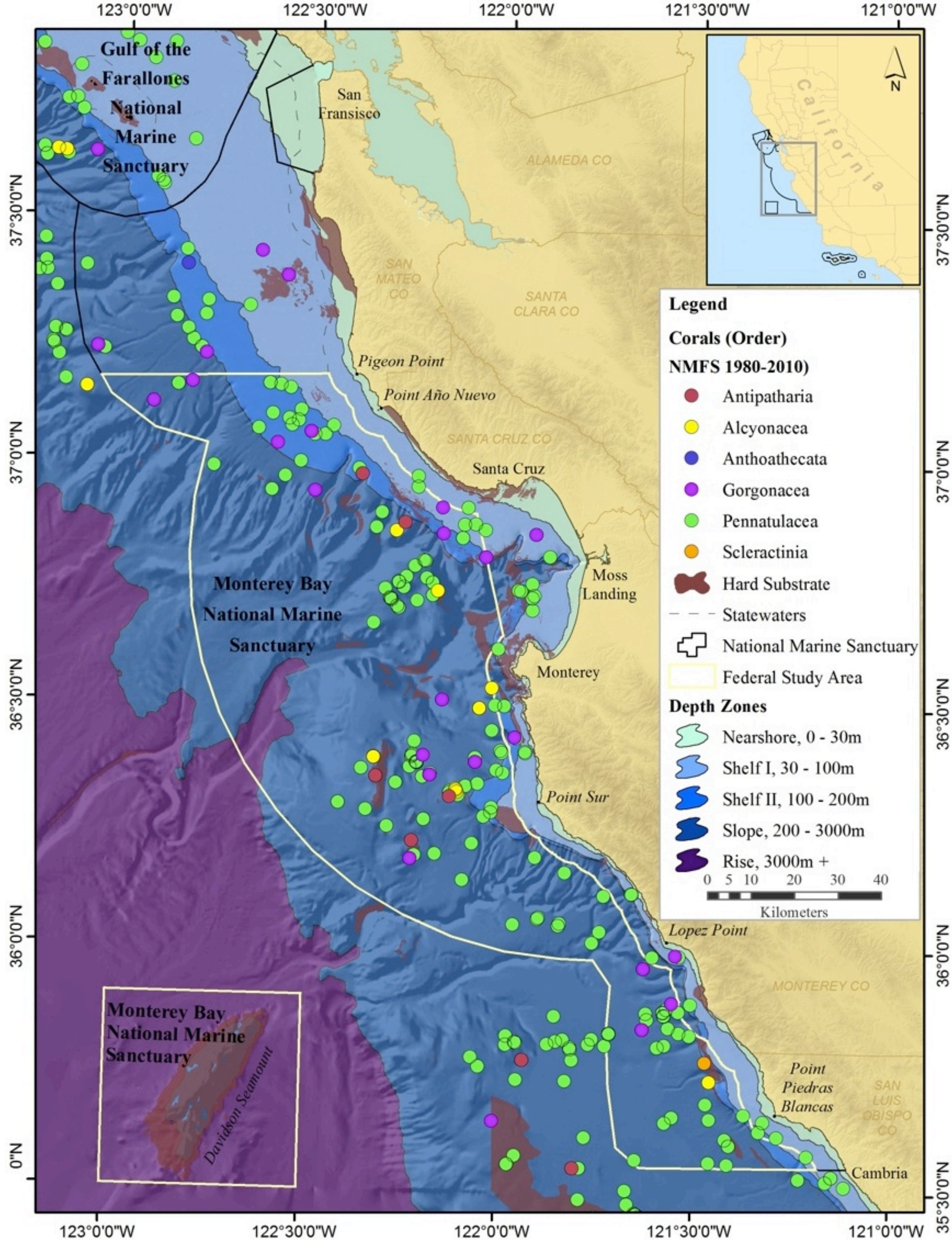

Figure 9. Corals collected in National Marine Fisheries Service groundfish trawl surveys.
Historical observations of cold-water/deep-sea corals from groundfish bottom trawl surveys conducted from 1980 to 2001 by the Alaska Fisheries Science Center and 2001 to 2010 by the Northwest Fisheries Science Center. These trawl surveys occurred primarily on soft substrates and were designed to survey groundfish. Data on corals represent incidental observations and do not adequately represent occurrences of coral communities (especially on undersampled hard bottoms). Data Credit: Northwest Fisheries Science Center

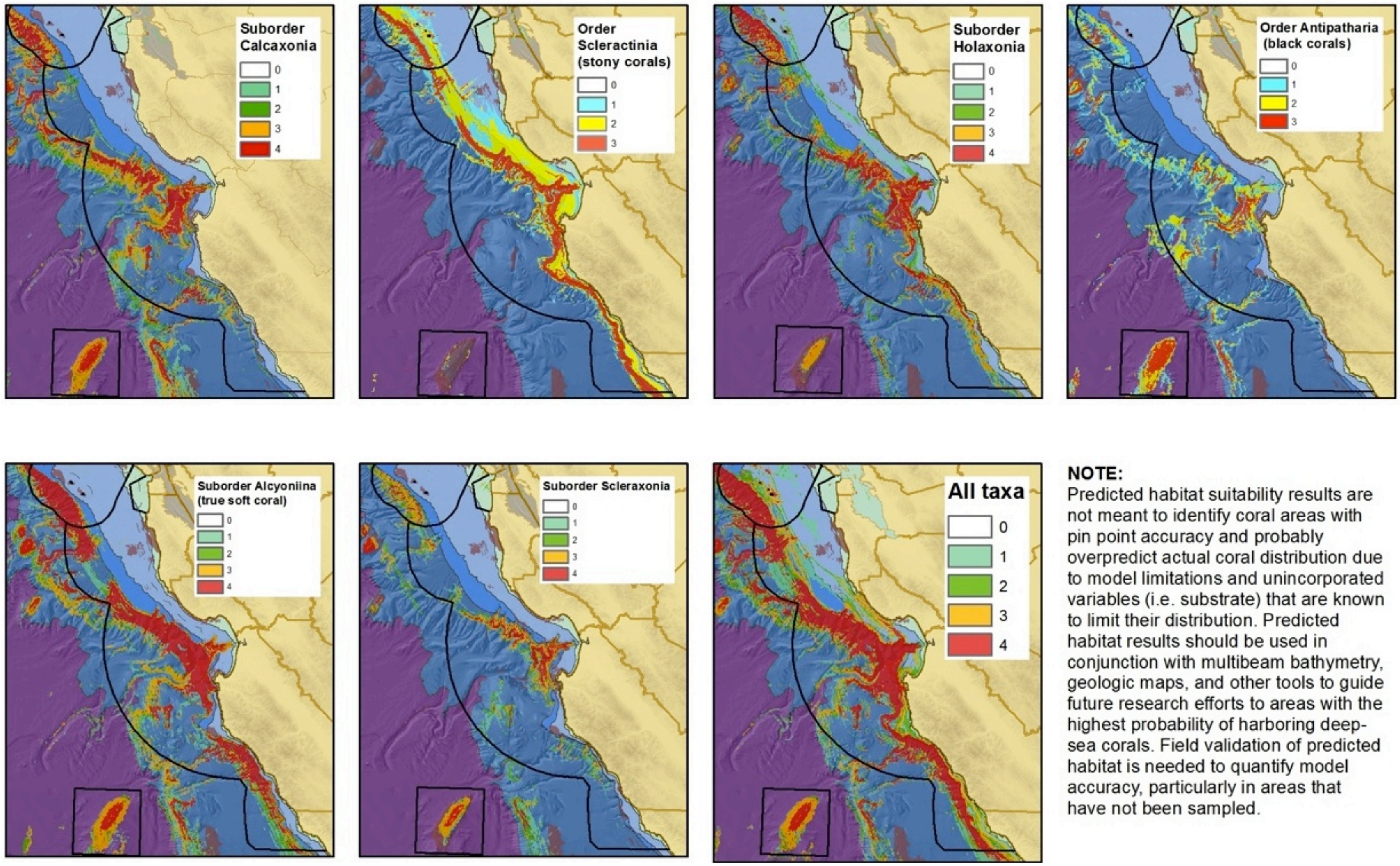

Figure 10. Predicted habitat suitability for six taxa of deep-sea coral.
Predictive habitat models for deep-sea corals in the U.S. West Coast Exclusive Economic Zone were developed by Guinotte and Davies (2012). The maps show the predicted suitability of benthic habitats in MBNMS for six taxa separately and for all taxa combined. The final number of models that predicted over 50 % coral presence per 500 m by 500 m grid are shown, with the maximum number of models per grid being 4 for suborders and 3 for orders. Models identified slope, temperature, salinity and depth as important predictors for most deep-sea coral taxa. Data credit: Guinotte and Davies 2012

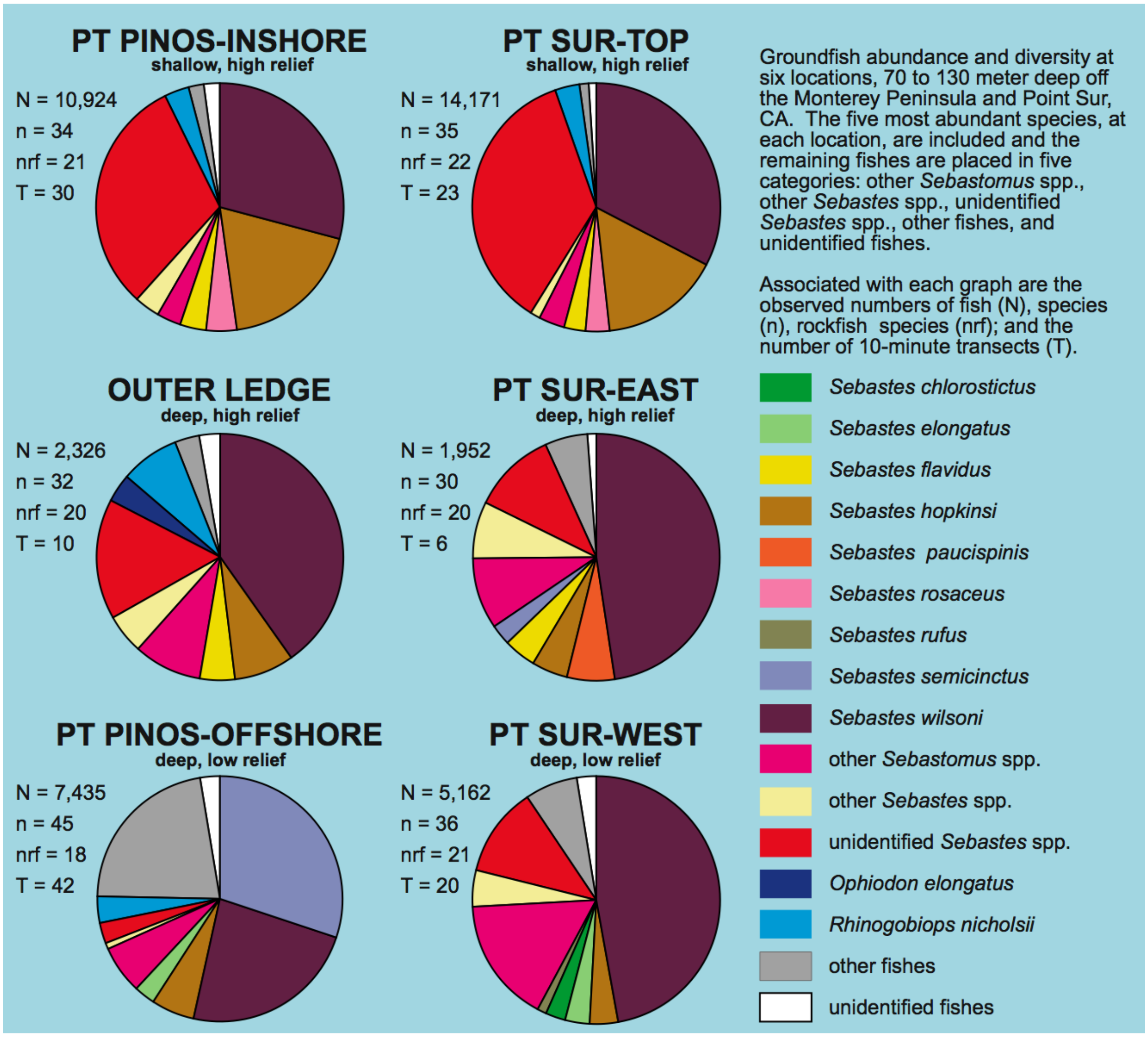

Figure 11. Groundfish abundance and diversity at Point Pinos and Point Sur.
Starr et al. (2006) measured groundfish abundance and diversity at six locations, 70 to 130 meters deep off Point Pinos and Point Sur. The five most abundant species, at each location, are included and the remaining fishes are placed in five categories: other *Sebastomus* spp., other *Sebastes* spp., unidentified *Sebastes* spp., other fishes, and unidentified fishes. Associated with each graph are the observed numbers of fish (N), species (n), rockfish species (nrf); and the number of 10-minute transects (T).

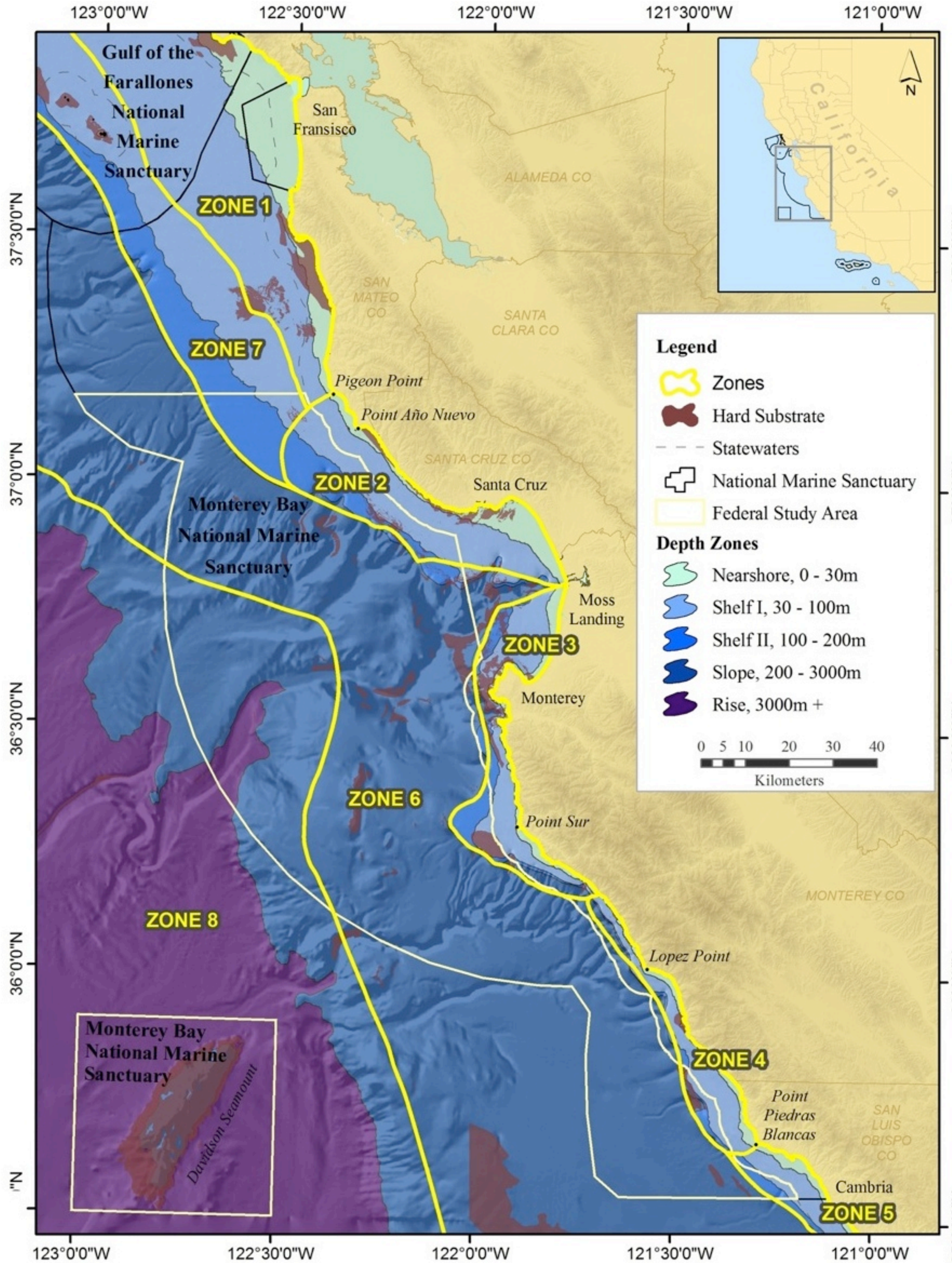

Figure 12. Location of eight zones for pelagic species off central California.
Eight zones identified by USGS, NOAA, and MLML seabird, marine mammal, and sea turtle experts in order to depict the overall distribution of pelagic species off central California (Research Planning Inc. 2006). The zones differ in depth, distance from shore, and other habitat features. Table 12 provides the relative abundance and seasonality of species and species groups in the zones.

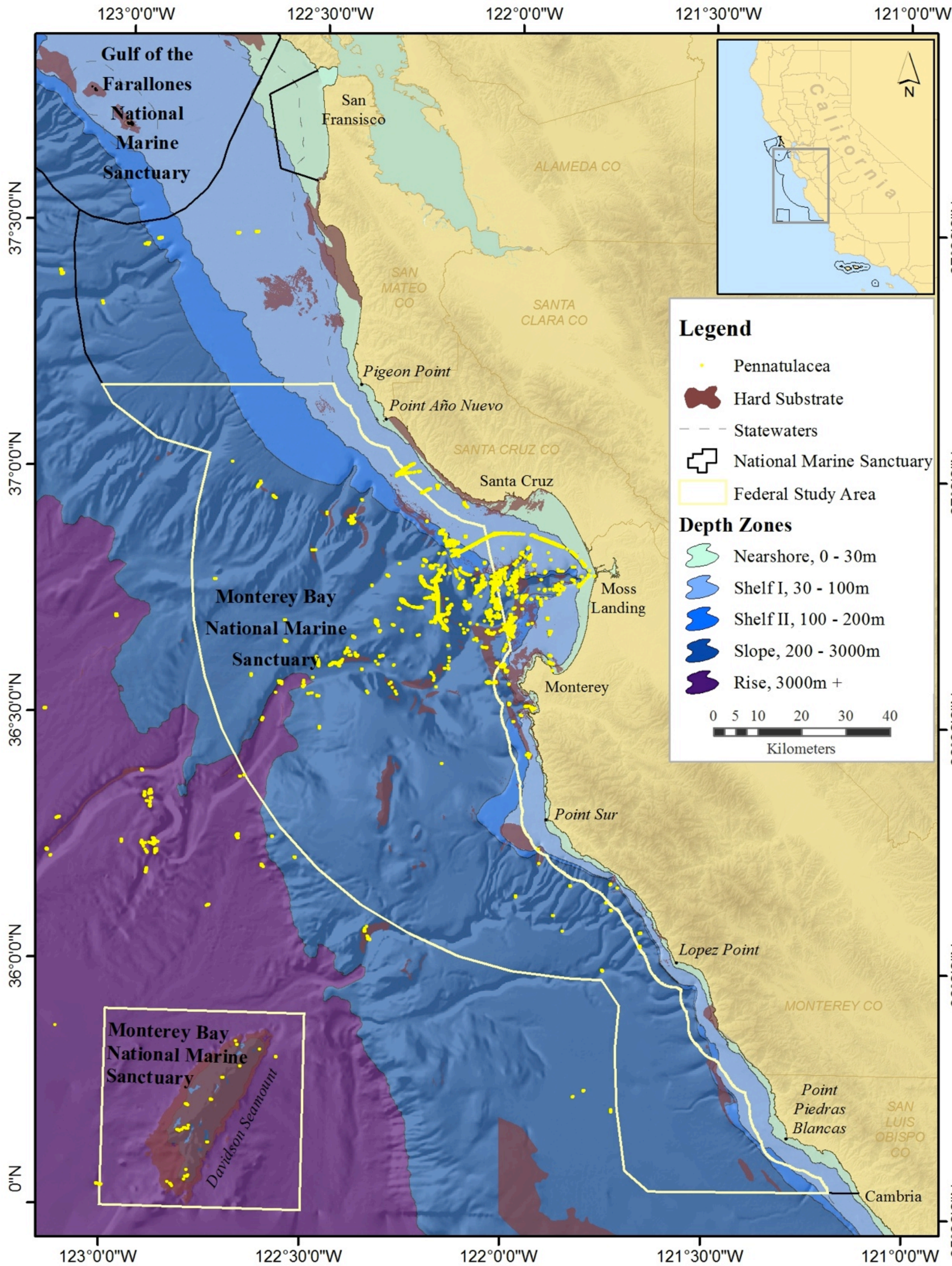

Figure 13. Observations of invertebrates associated with soft substrate.
Locations where sea pens (Order Pennatulacea) have been observed during Monterey Bay Aquarium Research Institute (MBARI) ROV surveys 1989-2009. Each data point represents a sighting regardless of the abundance of the organisms in the video frame. These organisms also occur in areas that have not been sampled by MBARI (survey effort not show). Data credit: Monterey Bay Aquarium Research Institute

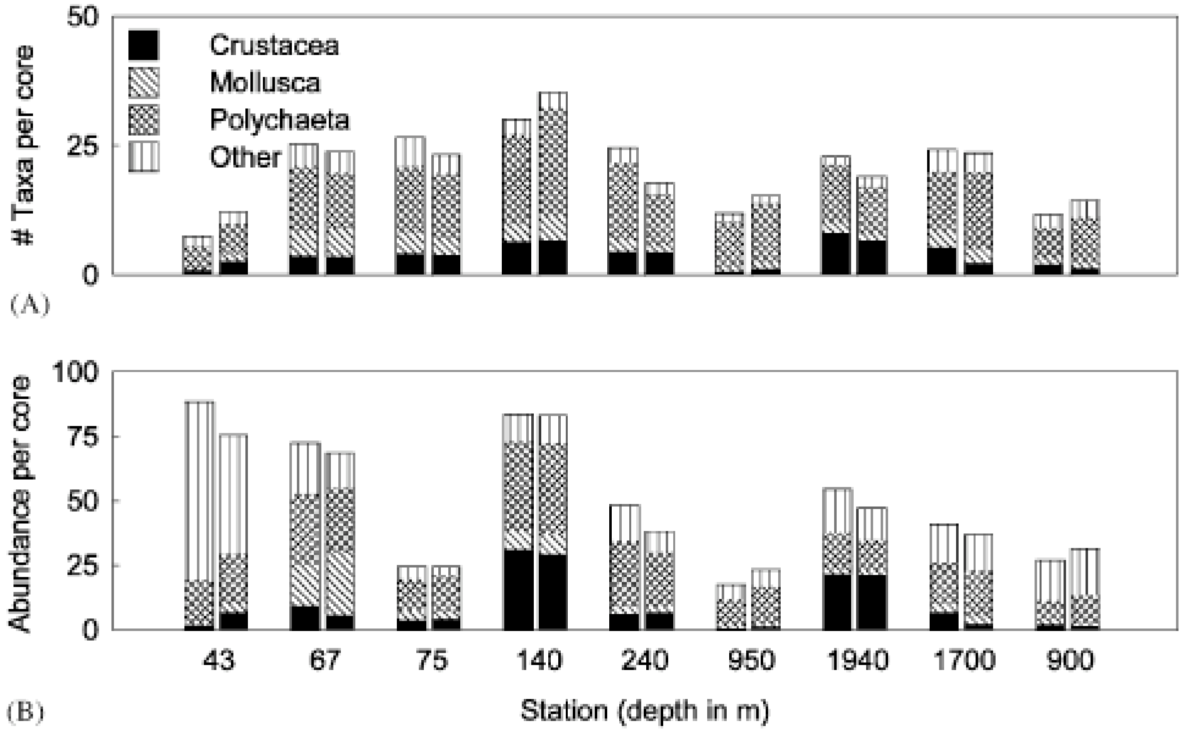

Figure 14. Number and abundance of infaunal taxa along a submarine cable in MBNMS.
The average number of infaunal taxa (A) and average abundance of infauna (B) per sample at each station in a survey along a submarine cable extending between Pillar Point and the Pioneer Seamount in the northern MBNMS (reprinted from Kogan et al. 2006). Samples consist of organisms from the upper 5 cm of sediments collected from 7 cm diameter push cores. Samples taken near a submarine cable (bars on the right) are compared to those taken from control sites (bars on the left). “Other’ category includes Cnidaria, Echinodermata, Echiuran, Nematoda, Nemertea, Phoronida, Pycnogonida, and Sipunculid.

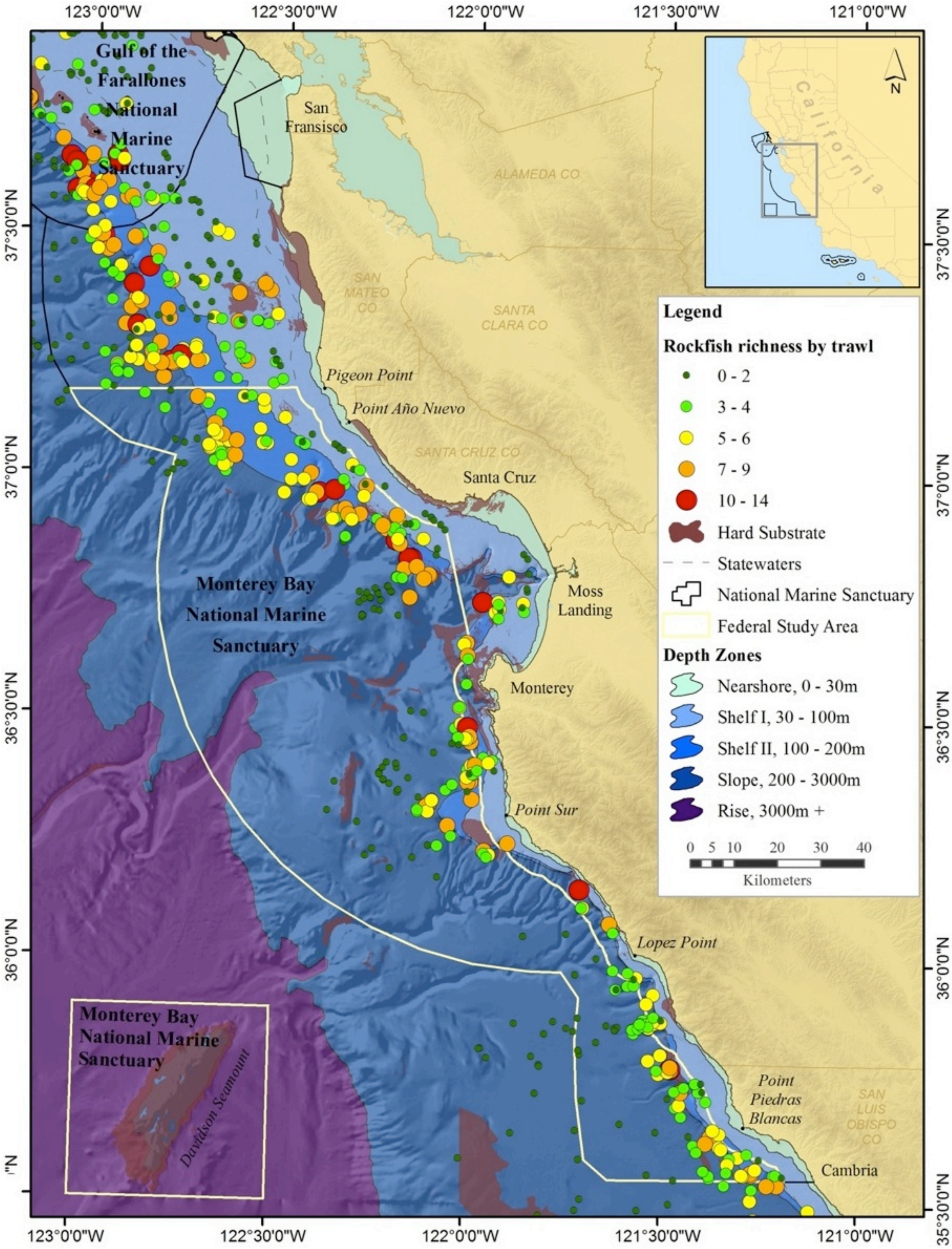

Figure 15. Species richness of demersal rockfishes.
Species richness of demersal rockfishes was calculated from NMFS shelf and slope trawls. Values were not influenced by latitude, but were highly influenced by depth. The highest rockfish richness values were observed along the edge between the shelf and slope (between 200 and 300 m depth). Data credit: NCCOS 2003

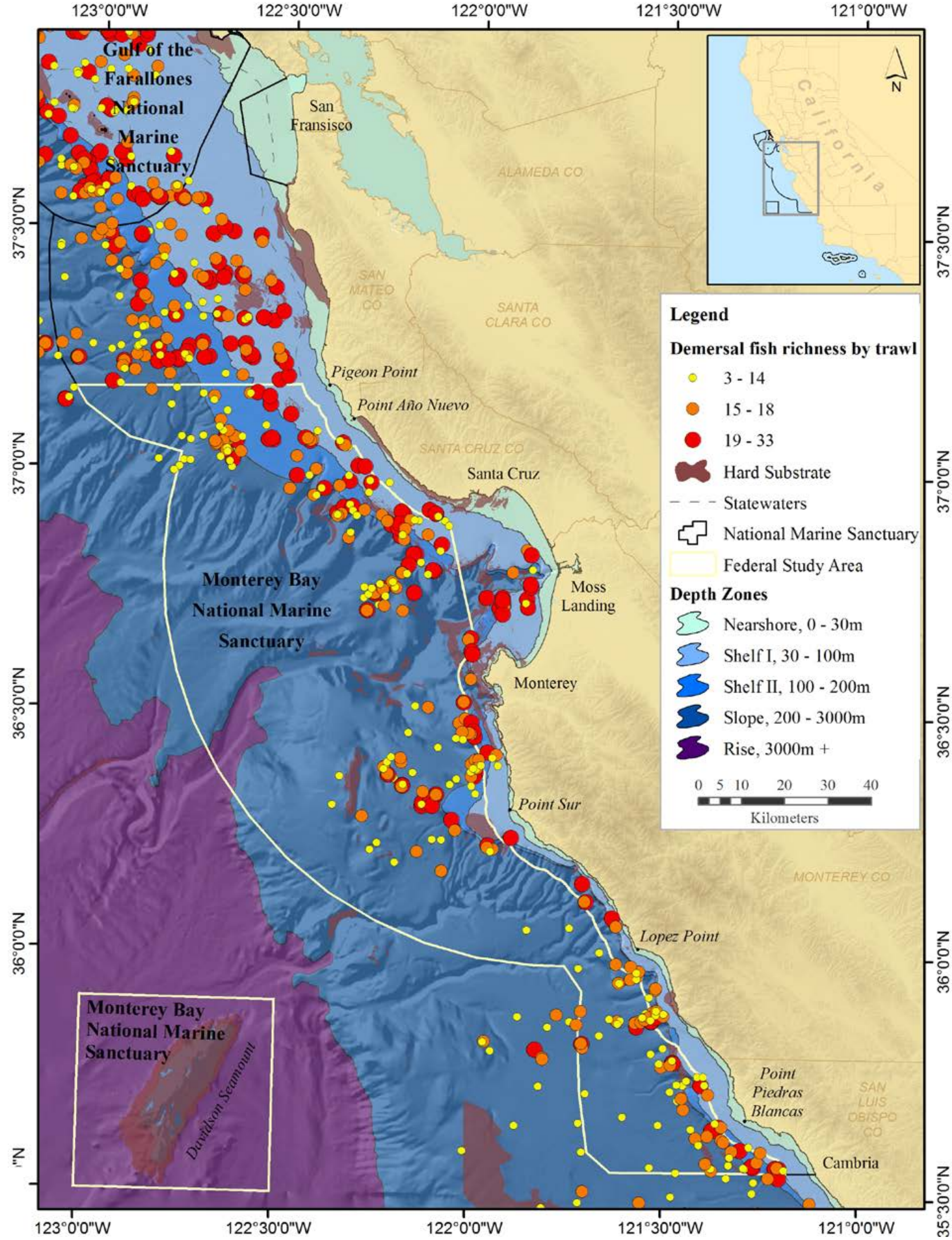

Figure 16. Species richness of demersal fishes.
Species richness of demersal fishes was calculated from NMFS shelf and slope trawls between 50 and 1280 m. The mean number of fish species recorded for trawls (± standard deviation) was 16 ± 5. Data credit: NCCOS 2003

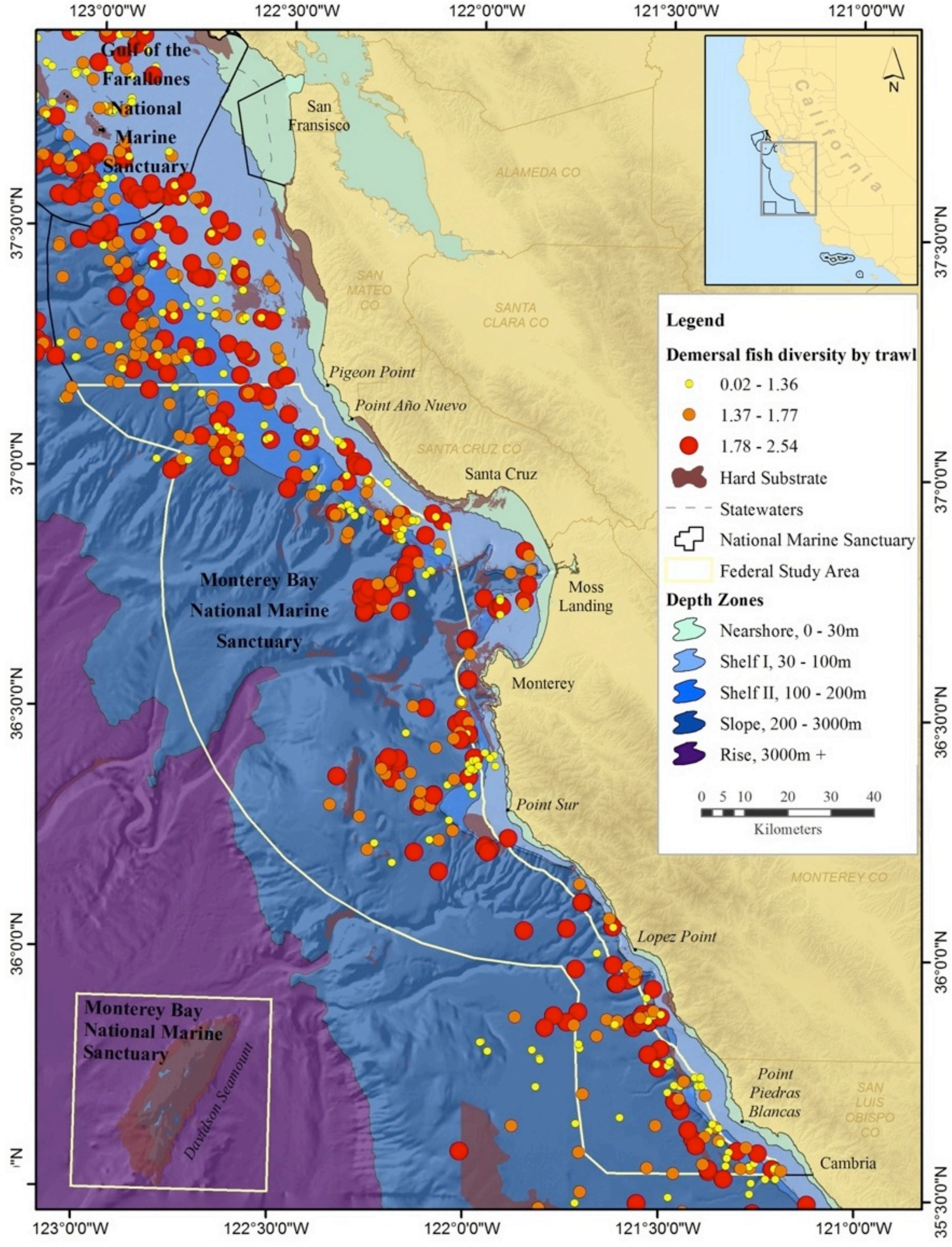

Figure 17. Species diversity of demersal fishes.
Species diversity of demersal fishes was calculated for NMFS trawls on the shelf and slope at depths between 50 and 1280 m. The mean diversity recorded for trawls (± standard deviation) was 1.5±0.5. The largest cluster of high species diversity trawls is found 20 km north and south of the border between Monterey Bay NMS and Gulf of the Farallones NMS. Data credit: NCCOS 2003

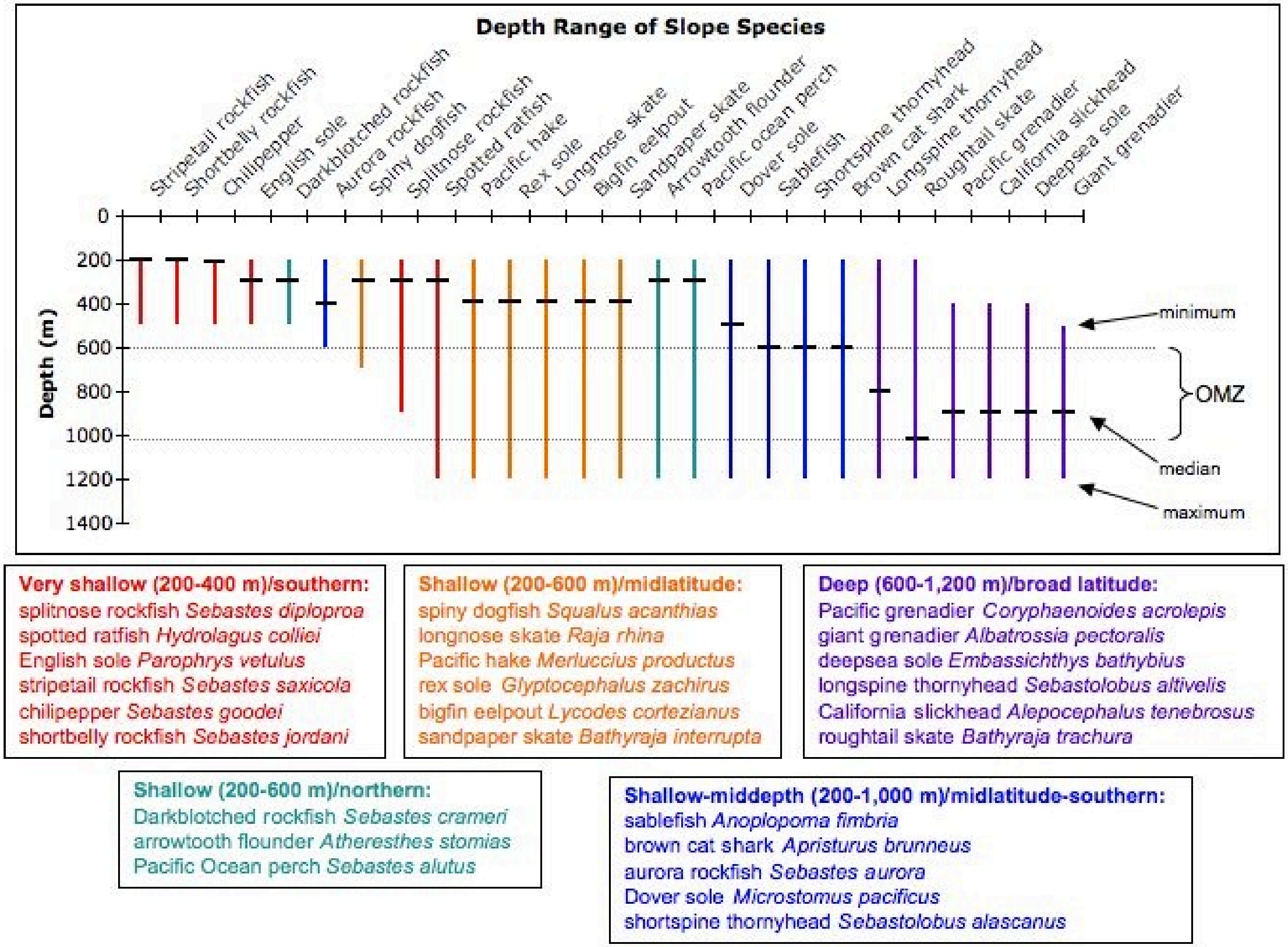

Figure 18. Depth range of groundfishes collected from slope trawl surveys.
Depth range (minimum, median and maximum in m) of groundfishes collected in fishery-independent slope trawl surveys conducted by the NMFS-NWFSC from 1977-2001 across the U.S. west coast (WA, OR, CA combined). Five species assemblages were identified based on depth and latitude (Tolimieri and Levin 2006).

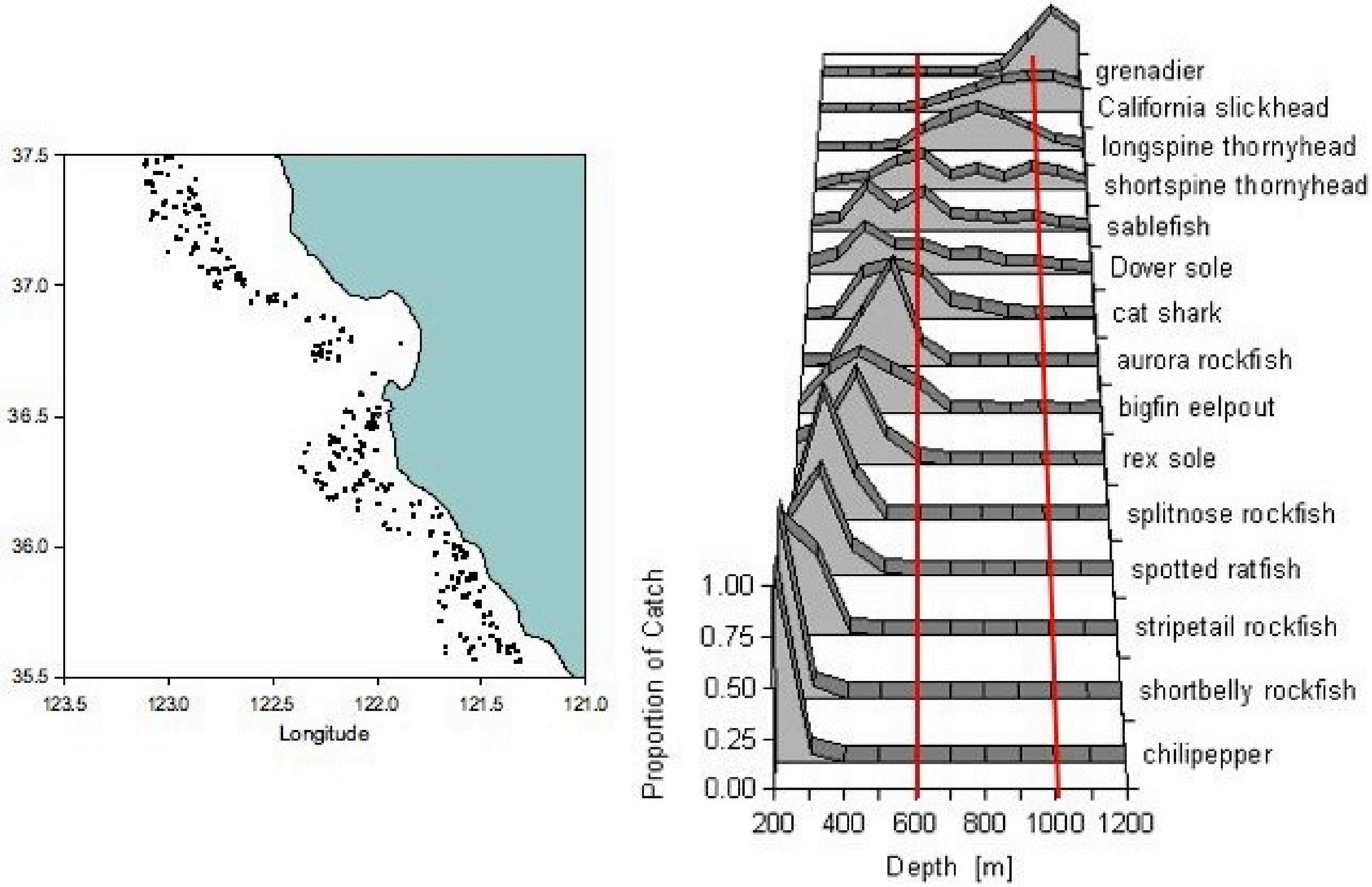

Figure 19. Depth distribution of continental slope species in MBNMS.
Depth distributions of continental slope species in the Monterey Bay National Marine Sanctuary based on NWFSC slope trawl survey data (1999-2006, N = 275 trawls). Sampling locations shown in left panel. Proportion of the catch of each species collected per 100 m depth interval shown in right panel (red lines designate upper and lower bounds of the OMZ). Data analysis provided by S. Ralston, NMFS-SWFSC. Original data courtesy of B. Horness, West Coast Groundfish Survey Program, NMFS-NWFSC.

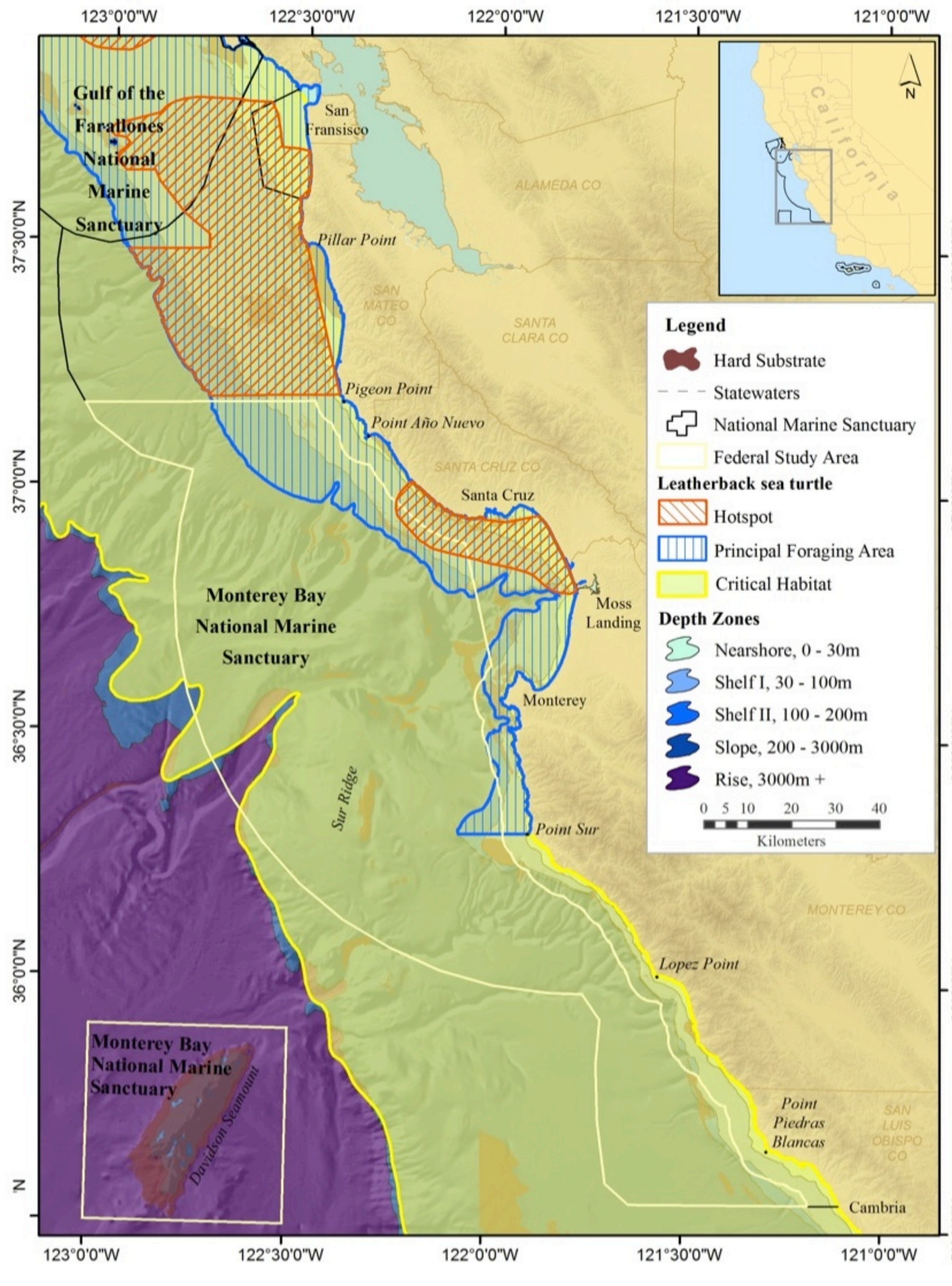

Figure 20. Hotspots, principal foraging area, and critical habitat for the leatherback sea turtle. Hotspots, areas where leatherback sea turtles have been encountered most frequently, were identified in central California by the offshore Environmental Sensitivity Analysis in 2006 and updated based on personal communication with Scott Benson (March 2012). The principal foraging area - part of Area 1 identified in Title 50 Code of Federal Regulations, Part 226.207 (77 Federal Register 4170) - includes the area between Point Sur and Point Arena extending offshore to the 200 m isobath. Critical habitat (77 Federal Register 4170) also includes offshore waters utilized by leatherbacks when prey availability in the principal foraging area is poor.

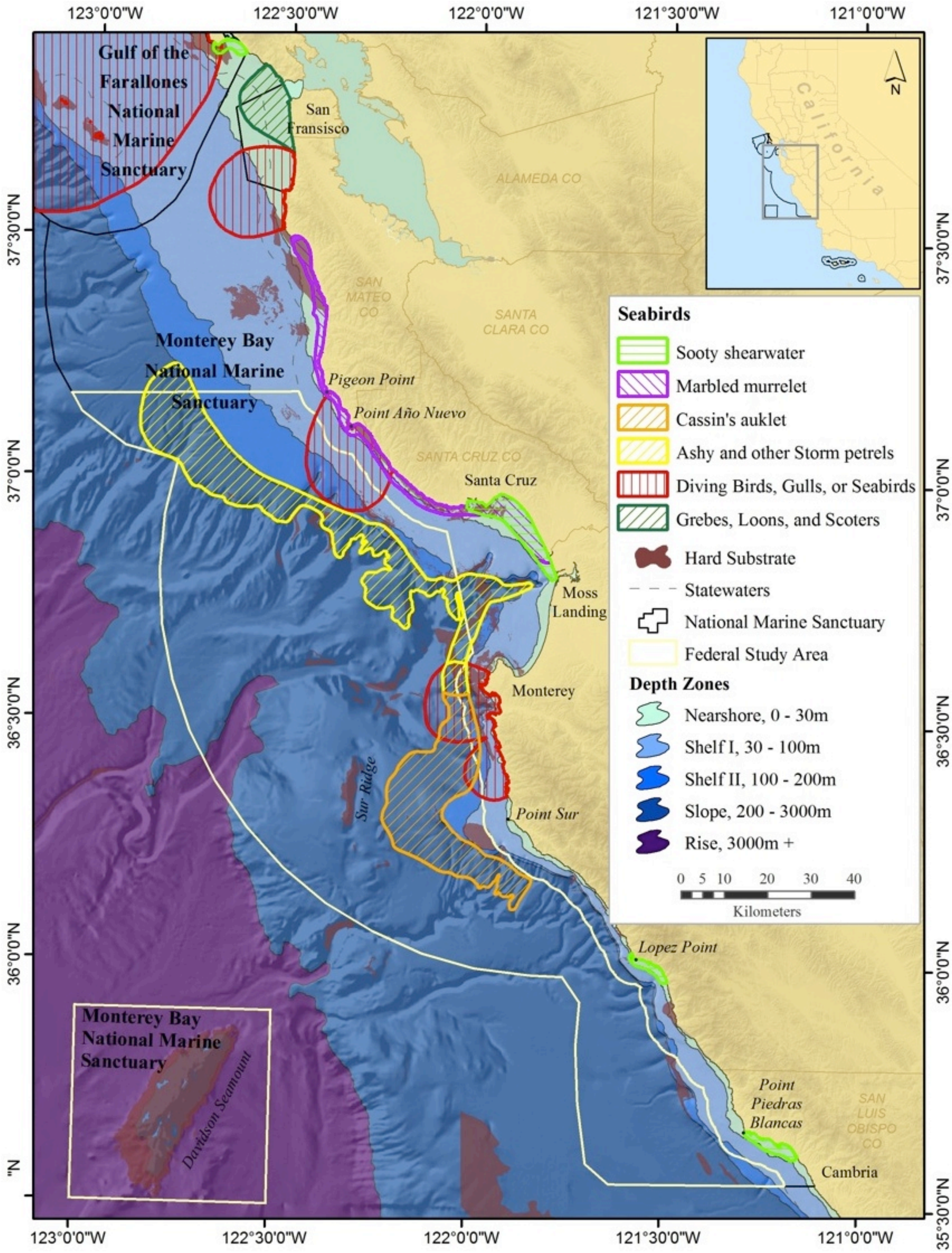

Figure 21. Hotspots for seabirds in MBNMS.
Locations of concentration, or 'hotspots', of seabirds were identified by USGS, NOAA, and MLML seabird, marine mammal, and sea turtle experts (Research Planning Inc. 2006). Hotspots tend to be areas with elevated abundance of prey or located adjacent to nesting habitats.

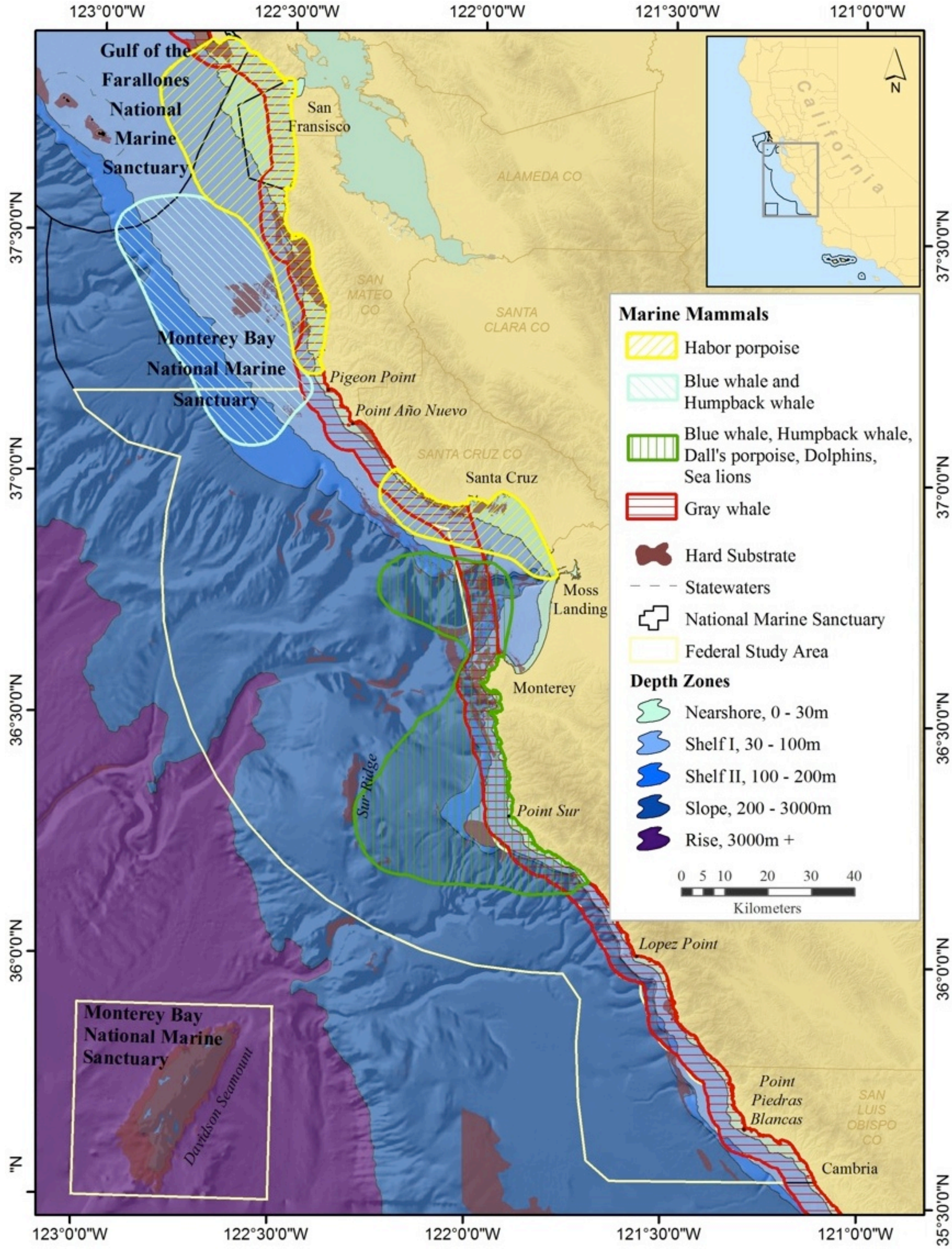

Figure 22. Hotspots for marine mammals in MBNMS.
Locations of concentration, or 'hotspots', of marine mammals identified by USGS, NOAA, and MLML seabird, marine mammal, and sea turtle experts (Research Planning Inc. 2006). Hotspots tend to be areas with elevated abundance of prey or located adjacent to rookeries or haul-outs.

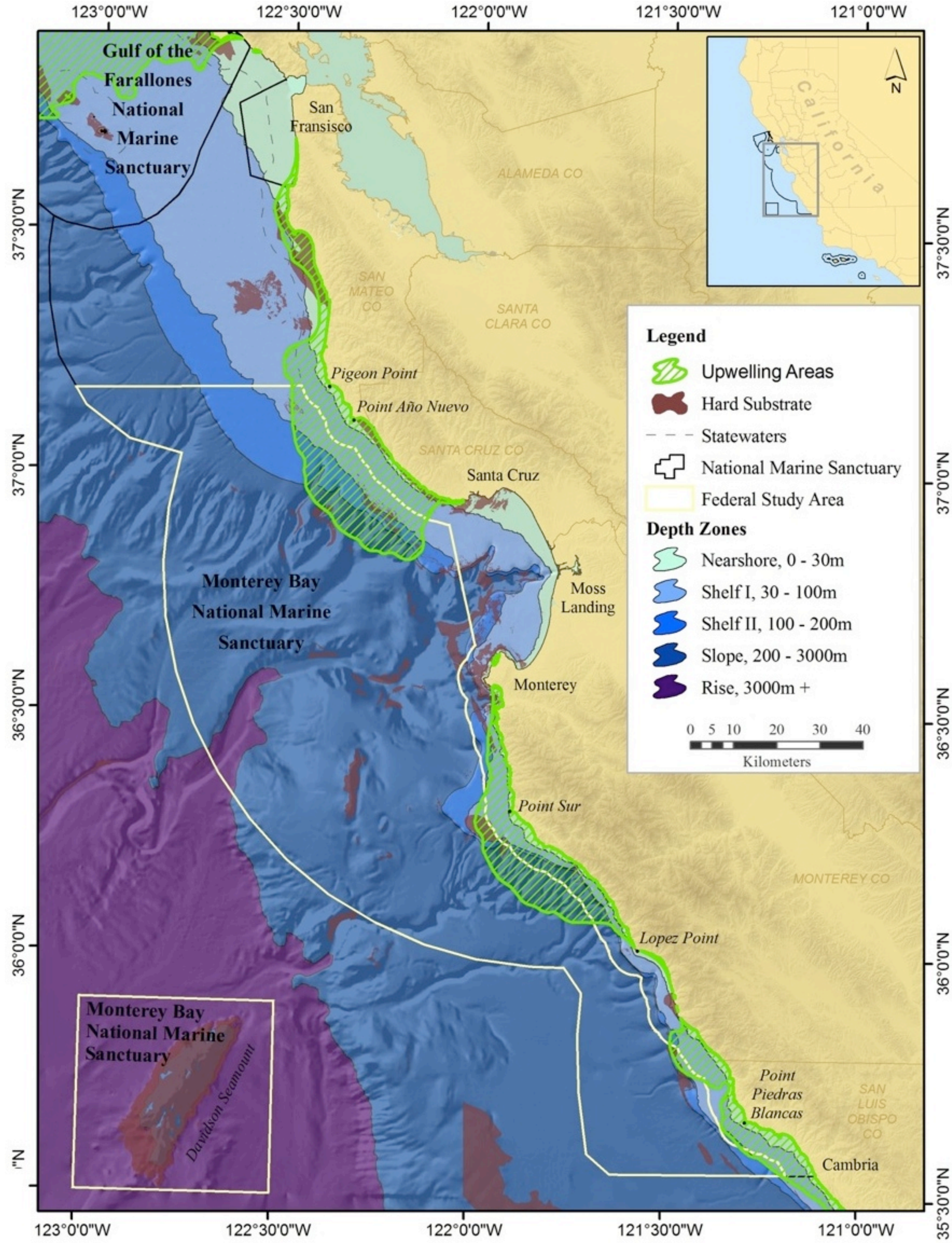

Figure 23. Persistent upwelling zones in MBNMS
The Nature Conservancy (2006) identified upwelling zones (green hatching) as areas with persistently cold (~9-12 ºC) sea surface temperature (SST) during the upwelling season (March-September). Data source: NOAA Coastwatch AVHRR data (March-September 1999-2002).

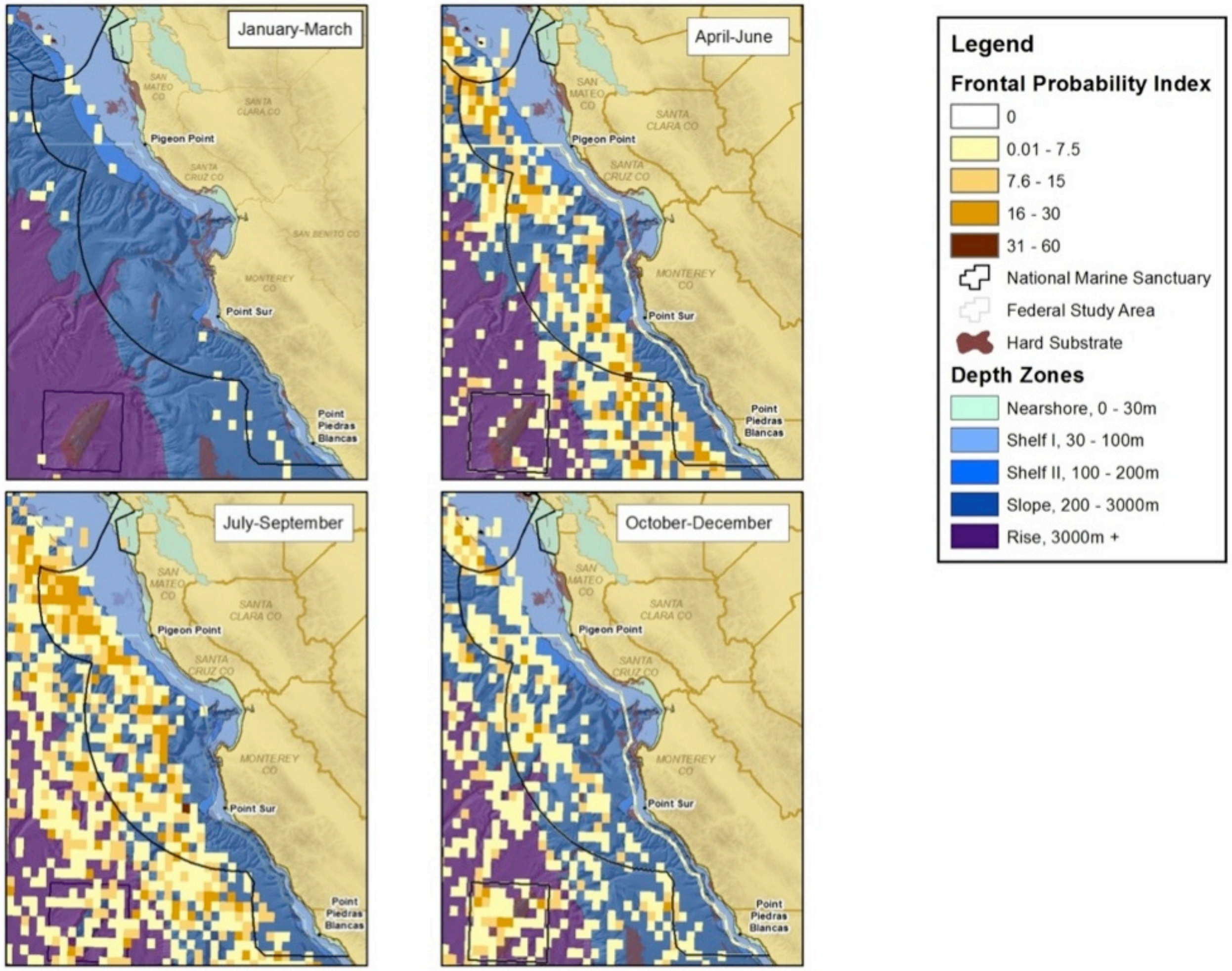

Figure 24. CoastWatch Oceanic Front Probability Index by season.
The CoastWatch Oceanic Front Probability Index (FPI) measures the probability of sea surface temperature front formation based on data from NOAA's GOES satellites. Daily average sea surface temperature (SST) is generated from the GOES data. Fronts are identified by applying an edge detection algorithm to this daily averaged SST field (Breaker et al. 2005). Pixels with gradients greater than 0.375 °C are classified as a front. The frontal probability index is then calculated as the number of times a pixel is classified as a front divided by the number of cloud free days per month. Pixels with a monthly FPI of 20% or greater are selected and averaged for all months within a given season, for the entire duration of the data set (2001-2006). Nearshore areas are not surveyed by the GOES data. Data source: Coastwatch 2007 (unpublished data).

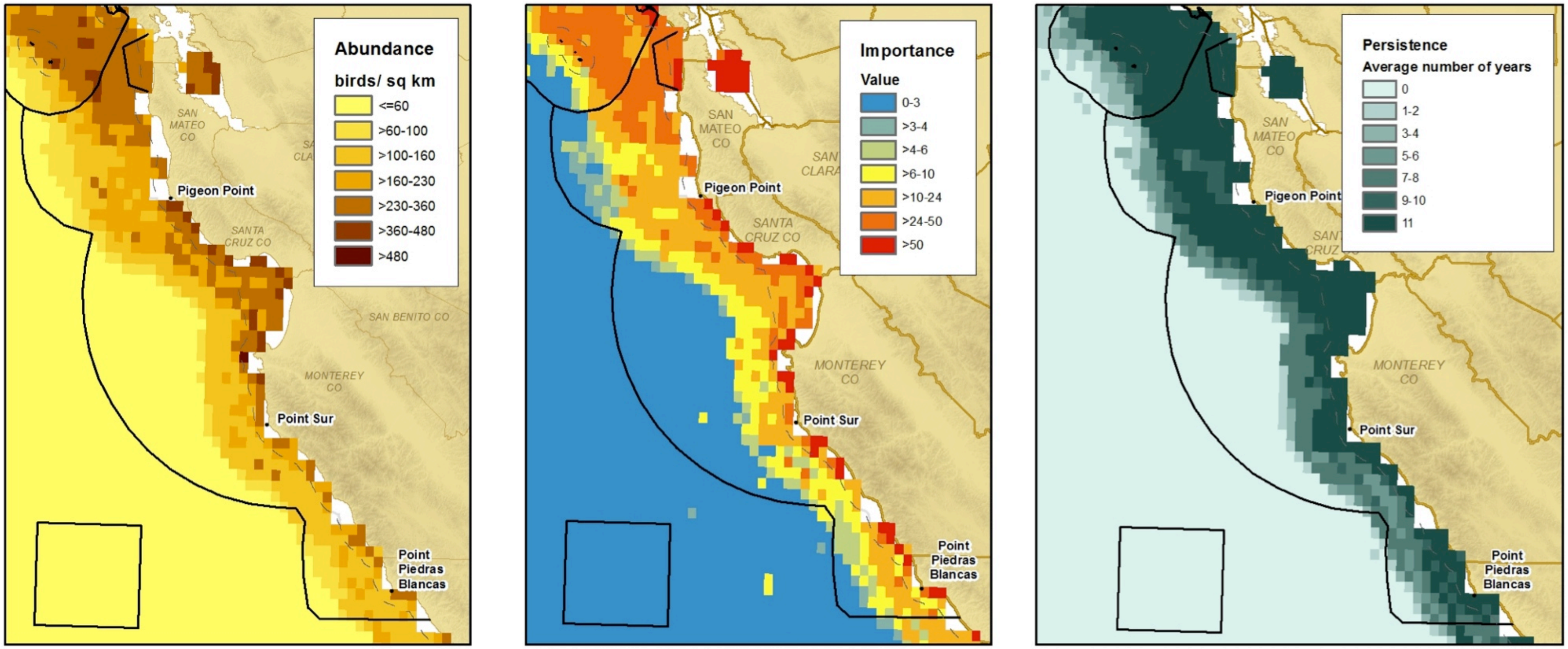

Figure 25. Modeled multispecies seabird hotspots in MBNMS.
Predicted hotspots of multispecies seabird aggregations in MBNMS based on spatial models developed for the California Current Ecosystem (Nur et al. 2011). Data from at-sea surveys of seabirds over an 11-year period (1997-2008) were combined with information on habitat features (bathymetry and oceanography) to predict hotspots for seabirds. Single species model predictions for 16 species were combined to identify potential multispecies hotspots using three criteria: abundance, importance, and persistence. The abundance values represent the summed, standardized abundance for all 16 species in number of birds per square kilometer. The importance values are "highest predicted density" cells with higher values representing higher predicted abundance of all species. The persistence values represent the number of years a cell was in the 95th percentile of all prediction cells, averaged over all species and seasons. The spatial scale of the models was 38.5ºN to 35ºN from the shoreline to 600 km offshore. Seabird species: Black-footed Albatross (*Phoebastria nigripes*), Bonaparte's Gull (*Larus philadelphia*), Brandt's Cormorant (*Phalacrocorax penicillatus*), Brown Pelican (*Pelecanus occidentalis*), Cassin's Auklet (*Ptychoramphus* aleuticus), California Gull (Larus californicus), Common Murre (*Uria aalge*), Fork-tailed Storm-Petrel (*Oceanodroma furcata*), Glaucous-winged Gull (*Larus glaucescens*), Heermann's Gull (*Larus heermanni*), Herring Gull (*Larus argentines*), Leach's Storm-Petrel (*Oceanodroma homochro*), Red-necked Phalarope (*Phalaropus lobatus*), Sabine's Gull (*Xema sabini*), Sooty Shearwater (*Puffinus griseus*), and Western Gull (*Larus occidentalis*). Data credit: PRBO Conservation Science.

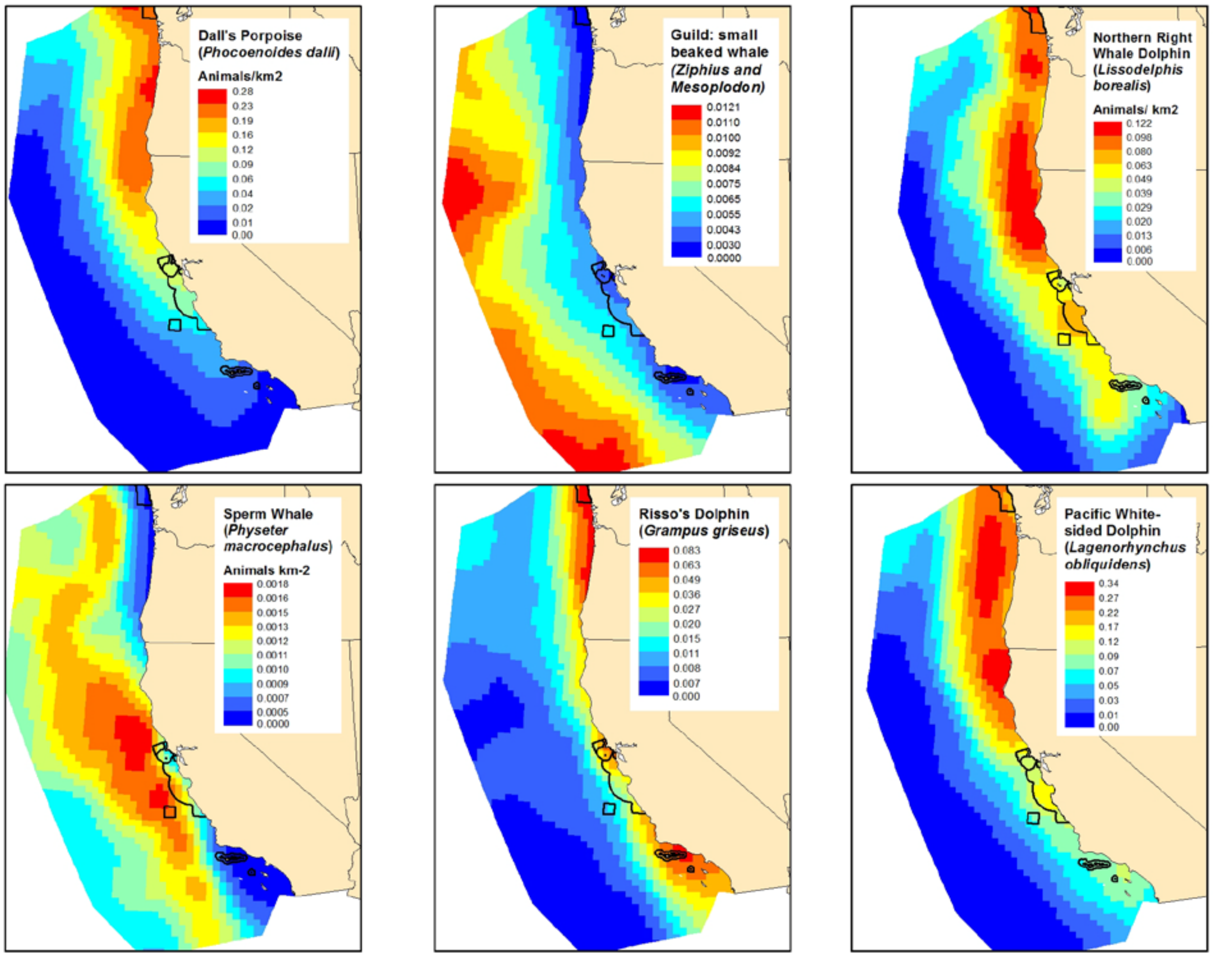

Figure 26. Modeled densities of whales in the California Current Ecosystem.

Sightings of whales from shipboard surveys (1991-2008) were combined with in situ and remotely sensed data of environmental variables and other measures of habitat (e.g., water depth, bathymetric slope) to develop predictive models of animal density. The best models were selected based on a collection of quantitative and qualitative methods. Ship survey data are from summer and fall seasons, corresponding to the "warm-season" for cetaceans in the California Current Ecosystem (CCE). Predicted transect segment densities for each year were smoothed with geospatial methods to obtain a continuous grid of density (animals per km^2) estimates for the CCE. Annual grids were averaged to obtain a composite grid of animal densities shown as 25 by 25 km grids. Black lines are the boundaries of the five National Marine Sanctuaries in the CCE. Data Credit: Barlow et al.2009, Forney et al. 2012, Becker et al. in review.

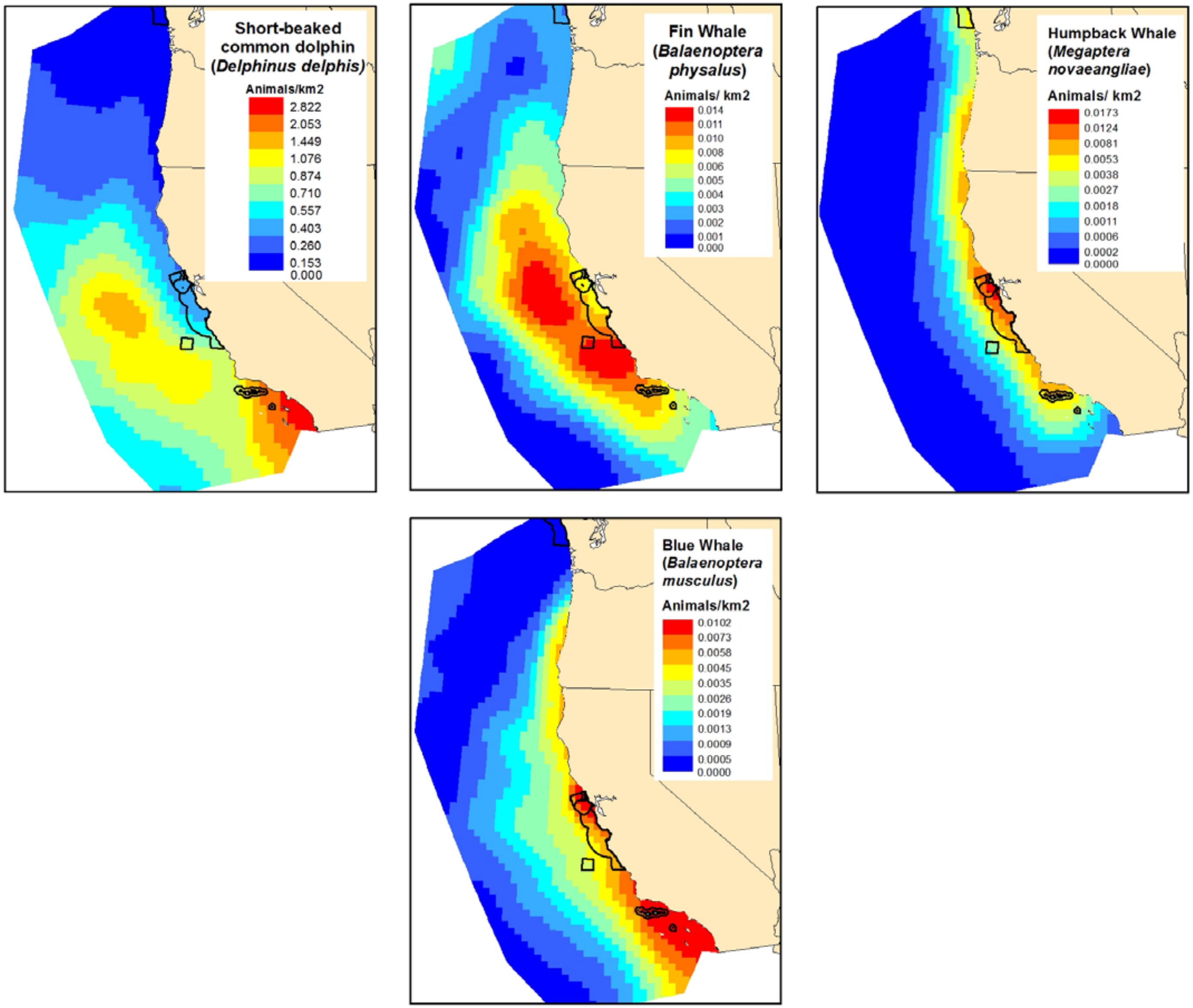

Figure 26. (con't.)

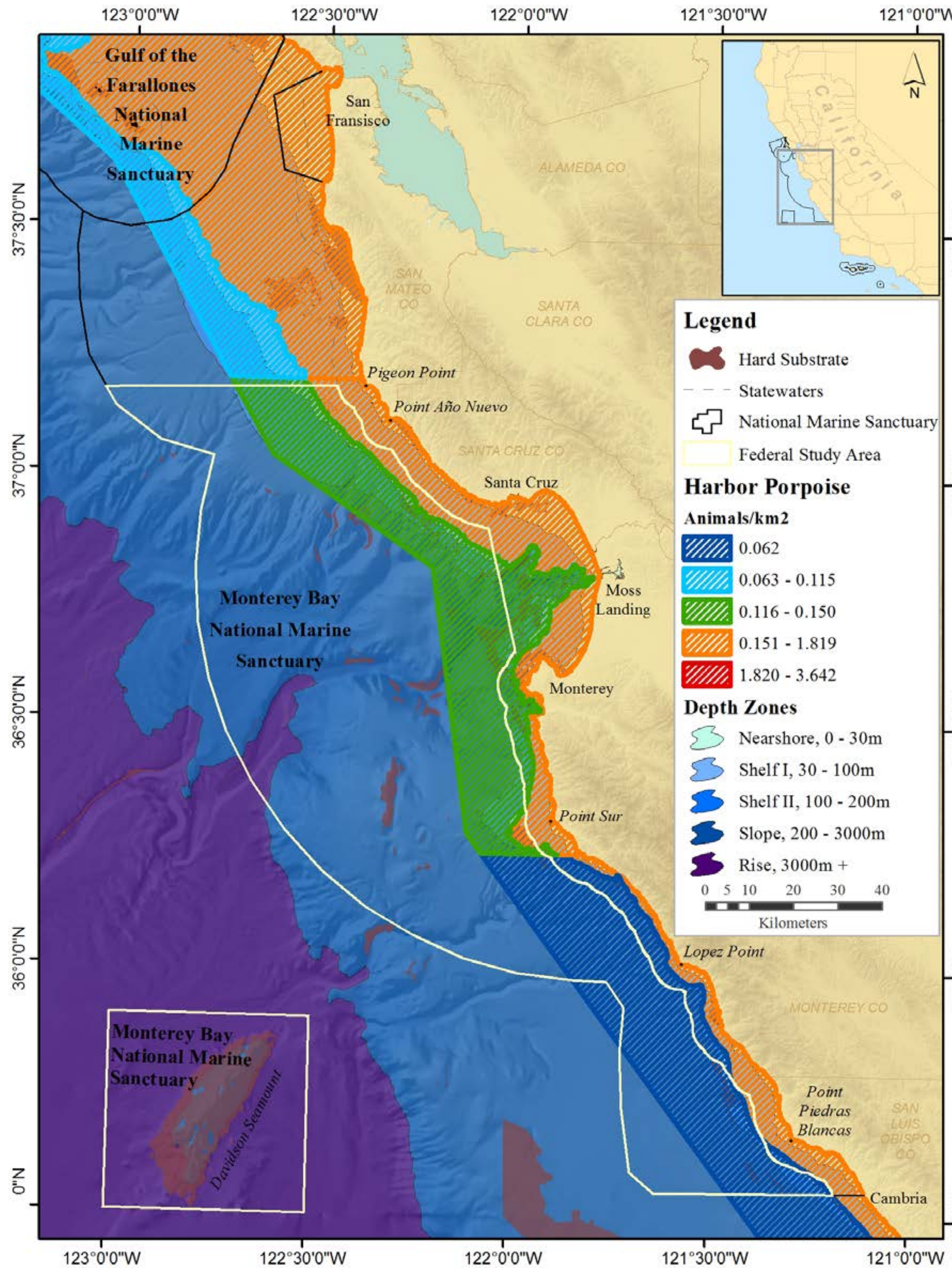

Figure 27. Stratified estimates of harbor porpoise density in MBNMS.

Carretta et al. (2009) compiled stratified estimates of harbor porpoise density in California waters from species-specific aerial surveys conducted between 2002-2007. Two sets of transects, one inshore (out to the 90 m isobath) and one offshore (between the 90 and 200 m isobath), were surveyed between the CA/OR border and Pt. Conception. The highest density category observed in this study (symbolized in red) is outside MBNMS and thus not shown on the map Data Credit: SWFSC 2009

Table 1. Search topics, definitions and search questions.
Search topics (left column) were used to find and compile information on offshore habitats in MBNMS. The right column provides a definition of the search topic and questions that were used to guide the literature review. Search topics were organized under four main themes: habitat function, habitat structure, movement and dispersal, and species of special interest. A literature review using these search topics was completed for each of the offshore habitat categories listed in Table 2.

Search Topic	Definitions and Search Questions
HABITAT FUNCTION	
***Functional Habitats*:**	
Nursery Habitat:	A habitat in which the juvenile phase of one or more species congregates. Does this habitat serve as a nursery for one or more species? Does a specific microhabitat provide higher quality habitat for juveniles? Does a specific habitat, or sites within the habitat, have relatively higher supply of juveniles (areas of high settlement and/or recruitment)?
Feeding Ground:	An area used by a species for feeding. Is this habitat, or a specific area within the habitat, a foraging location for one or more species? Is the feeding ground year-round or seasonal?
Spawning/Breeding Ground:	An area used by a species for reproduction. Is this habitat, or a specific area within the habitat, used for spawning/breeding by one or more species? Is the spawning/breeding ground year-round or seasonal?
Migratory Corridor:	A path used by a species to move from one area to another (e.g., between spawning and feeding grounds). Does this habitat, or specific area within the habitat, serve as a migratory corridor for one or more species? When does the species use the migratory corridor?
Biogenic Habitat:	A habitat created by a living organism (e.g., plants or animals). Is some of the physical structure of this habitat formed by living organisms? Is the biogenic habitat used by other organisms?
Energy Flow:	
Primary Production:	The conversion of inorganic carbon (e.g., carbon dioxide, methane) into organic carbon (food) by photosynthesis or chemosynthesis.
Macrophytes:	A plant or alga that is easily seen without aid of a microscope. Are macrophytes a significant source of primary productivity in this habitat? What amounts of primary production (grams of carbon fixed / area / time) are observed in this habitat?
Phytoplankton:	The photosynthetic component of the plankton consisting primarily of single-celled algae and bacteria. Are phytoplankton a significant source of primary productivity in this habitat? What amounts of primary production (grams of carbon fixed / area / time) are observed in this habitat?
Chemoautotrophs:	Organisms that produce organic carbon through chemosynthesis. Are chemoautotrophs a significant source of primary productivity in this habitat? What amounts of primary production (grams of carbon fixed / area / time) are observed in this habitat?
Benthic-Pelagic Coupling:	The two-way exchange, or flux of matter, between the benthos and the overlying water body. Does benthic-pelagic coupling have a significant role in the proper functioning of this habitat? What is the rate of vertical particle flux?

Search Topic	Definitions and Search Questions
Key Trophic Interactions:	Trophic interactions that are necessary to the proper functioning of the ecosystem. Which trophic interactions are "key" in this habitat? How would the ecosystem be negatively impacted if the key interactions were lost or modified?.
Key Trophic Cascades:	Trophic cascades that are necessary to the proper functioning of the ecosystem. Are there any "key" trophic cascades in this habitat? Which species or species assemblages are at each tropic level in the cascade. How would changes in the trophic cascade impact the function of the focal ecosystem?
Productivity Hotspots:	A place of higher than usual productivity. Have any productivity hotspots been identified in the focal habitat? If so, where are they located? Are they always present or only present at certain times of year?
HABITAT STRUCTURE	
Species Composition:	The assemblage of species that are characteristic of an area. What species assemblages are characteristic of the habitat? Do different sites or microhabitats differ in their species assemblages?
Species Composition Shifts:	Have shifts in species composition been observed in this habitat? What are the possible causes, either natural or human-induced, of the shift?
Species Diversity and Species Richness:	An index of the number species in a system (i.e., species richness) and their relative abundance. What is the typical species diversity and species richness in this habitat? Are there certain microhabitats or sites with higher or lower than average species diversity or richness?
Biomass:	The total quantity or weight of organisms in an area. What is the typical biomass in this habitat? Are there certain microhabitats or sites with higher or lower than average biomass?
Key Species Interactions	Species interactions (e.g., predation, competition, mutualism, facilitation) that are characteristic of this habitat or important to maintaining the structure or function of the habitat. Which species interactions are characteristic of the habitat? Are certain species interactions key to maintaining habitat structure and function?
MOVEMENT AND DISPERSAL	The ontogenetic, seasonal, and daily movement patterns exhibited by juvenile and adults stages of mobile species. What types of movement patterns are exhibited by the mobile species in this habitat? Do some species use this habitat during ontogenetic movement? Describe the scale of these movements. Do some species have home ranges or exhibit territorial behavior? If so, what is the average size of a territory or home range?
SPECIES OF SPECIAL INTEREST	Species in MBNMS that receive relatively greater interest and attention from resource managers. This interest is due to a variety of factors, including ecological role, sensitivity to disturbance, low population size, or economic value. What species in the focal habitat are of special interest to resource managers?
Species landed in MBNMS	Species commonly caught and/or sold in the commercial fishery and recreational fishery in MBNMS. Which species that occur in the focal habitat are landed by fisheries?

Search Topic	Definitions and Search Questions
Endangered and Threatened Species	Species or populations that have been listed under the federal Endangered Species Act (ESA) or California Endangered Species Act (CESA). Which ESA and CESA listed species occur in the focal habitat?
Other "At Risk" Species	Species that have been listed as "Critically Endangered", "Endangered" or "Threatened" on the International Union for Conservation of Nature Red List, species listed as “Candidate Species” or "Species of Special Concern” under the ESA or CESA, and fish stocks listed as "Overfished" by the National Marine Fisheries Service. Which other “at risk” species occur in the focal habitat?

Table 2. Area of benthic habitats in Monterey Bay National Marine Sanctuary.
The area of each primary benthic habitat (as defined by depth zone and substrate type) and the percent area of the habitat in the entire MBNMS and in the federal study area are provided. Submarine canyon, oxygen minimum zone, and seamount are secondary habitat types (i.e., they overlap the primary benthic habitat categories). The areas of secondary habitats were calculated independently. The nearshore habitat is shaded grey because it does not occur in the federal study area.

Habitat Name	Depth Range (m)	Substrate Type	Area in entire MBNMS (km^2)	% of entire MBNMS	Area in Federal Study Area (km^2)	% of Federal Study Area
Nearshore	0-30	Hard	140	0.89	0	0.00
Nearshore	0-30	Soft	574	3.64	0	0.00
Shelf I	30-100	Hard	196	1.24	42	0.38
Shelf I	30-100	Soft	2546	16.13	338	3.08
Shelf II	100-200	Hard	69	0.44	33	0.30
Shelf II	100-200	Soft	1115	7.06	619	5.63
Slope	200-3,000	Hard	507	3.21	466	4.24
Slope	200-3,000	Soft	8740	55.37	7598	69.11
Rise	>3,000	Hard	176	1.12	176	1.60
Rise	>3,000	Soft	1720	10.90	1720	15.65
Submarine Canyon	various	Hard	189	1.20	126	1.15
Submarine Canyon	various	Soft	2380	15.08	1993	18.13
Oxygen Minimum Zone	600-1,000	Hard	58	0.37	48	0.44
Oxygen Minimum Zone	600-1,000	Soft	2283	14.47	1896	17.25
Seamount	1,250-3,530	Hard	373	2.37	373	3.40
Seamount	1,250-3,530	Soft	27	0.17	27	0.25

Table 3. Invertebrate species of special interest in MBNMS.

Invertebrate species in MBNMS that receive relatively greater interest and attention from resource managers, including species that are landed by fisheries in MBNMS. Only species that occur in offshore habitats of MBNMS during one or more life stage were included. Habitat categories are defined in Table 2. When available, the current population size/biomass relative to the historically high population size/biomass and the recent trend in population size are provided; increasing trend (↑), decreasing trend (↓), trend not significant (NS), unknown (unk). Population status information in red ink denotes information that is more than 5 years old (pre-2007). No invertebrate species in the study area qualified for the categories 'Endangered and Threatened species' or 'other at-risk species" so these categories were not included in the table. J = juvenile life stage; A = adult life stage. * = several species

Scientific Name/ Taxonomic Group	Common Name	Landed in MBNMS	Population Status		Habitat Categories									
			Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
Phylum Porifera	Sponges*					J, A		J, A		J, A		J, A		J, A
Order Antipatharia	Coral, black*					J, A		J, A		J, A		J, A		
Order Scleractinia	Coral, stony*					J, A		J, A		J, A		J, A		J, A
Order Alcyonacea (including Gorgonacea)	Coral, soft* (including sea fans and sea whips)					J, A		J, A		J, A		J, A		
Order Pennatulacea	Sea pens*					J, A			J, A		J, A		J, A	J, A
Family Stylasteridae	Hydrocorals*					J, A		J, A		J, A		J, A		J, A
Metridium spp.	Plumose anemones					J, A		J, A		J, A		J, A		J, A
Phylum Brachiopoda	Brachiopods*					J, A		J, A		J, A		J, A		J, A
Haliotis rufescens	Abalone, red		< 40%[1,2]	↓ or NS [1,2]								J, A		J, A
Kelletia kelletii	Whelk, Kellet's		unk[8]	unk[8]						J, A	J, A	J, A	J, A	J, A
Tresus spp.	Clam, gaper*	X	unk[3]	NS[3]									J, A	J, A
Octopus spp.	Octopus*	X		NS[4,5]						J, A	J, A	J, A	J, A	J, A
Doryteuthis (=Loligo) opalescens	Squid, market	X	unk[6]	unk[6]	J, A								J, A	J, A
Euphausia pacifica	Krill				J, A	J, A								
Thysanoessa spinifera	Krill				J, A	J, A								
Pandalus platyceros	Prawn, spot	X	unk[6]	unk[6]								J, A	J, A	J
Cancer magister	Crab, Dungeness	X	unk[7]	NS[7]					A		A		J, A	J, A
Lopholithodes foraminatus	Crab, box	X				J, A		J, A		J, A		J, A		J, A

Scientific Name/ Taxonomic Group	Common Name	Landed in MBNMS	Population Status		Habitat Categories									
			Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
Cancer antennarius	Crab, brown rock	X	unk[7]	↓ or NS[4,5]								J, A	J, A	J, A
Cancer productus	Crab, red rock	X	unk[7]	↓ or NS[4,5]		J, A		J, A		J, A		J, A		J, A
Parastichopus spp.	Cucumber, sea*	X	unk[6]	unk[6]								J, A	J, A	J, A
Class Crinoidea	Crinoids*					J, A		J, A		J, A		J, A		
Mesocentrotus (=Strongylocentrotus) franciscanus	Urchin, red	X	unk[7]	NS or↓[7]								J, A		J, A

[1] CDFG 2010a, [2]CDFG 2008a, [3] Leet et al. 2001; [4] Starr et al. 2002a; [5] based on CPUE data, [6] CDFG 2008b, [7] CDFG 2004, [8] CDFG 2010b

Table 4. Fish species of special interest in MBNMS.

Fish species in MBNMS that receive relatively greater interest and attention from resource managers, including species landed in MBNMS, Endangered and Threatened species (E/T) , and other ‘at risk’ species (defined in Table 1). Only species that occur in offshore habitats of MBNMS during one or more life stage were included. Habitat categories are defined in Table 2. When available, the current population size/biomass relative to the historically high population size/biomass and the recent trend in population size are included; increasing (↑), decreasing (↓), trend not significant (NS), or unknown (unk). Population status information in red ink denotes information that is more than 5 years old (pre-2007). SSC = Species of Concern; VU = Vulnerable; EN = Endangered; OF = Overfished. J = juvenile life stage; A = adult life stage.

Taxonomic Group	Scientific Name	Common Name	Landed	E/T	At-Risk	Population Status		Habitat Categories									
						Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - Soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
Hagfishes	*Eptatretus deani*	Hagfish, black	X									J, A					
	Eptatretus stoutii	Hagfish, Pacific	X			unk[1]	unk[1]		J, A			J, A		J, A		J, A	J, A
Sharks, cow	*Hexanchus griseus*	Shark, bluntnose six gill	X			unk[2]	unk[2]	J, A	A								
	Notorynchus cepedianus	Shark, broadnose seven gill	X			unk[2]	unk[2]	J, A							A	J, A	J, A
Sharks, dogfish	*Squalus suckleyi*	Shark, spiny dogfish	X			63%[3]	↓[3]	J, A									
Sharks, thresher	*Alopias vulpinus*	Shark, thresher	X			unk[4]	↑[4]	J, A									
Sharks, basking	*Cetorhinus maximus*	Shark, basking			SSC, EN	10%[28]	↓ or NS[28]	J, A									
Sharks, mackerel	*Carcharodon carcharias*	Shark, white			VU	unk[2]		J, A									
	Isurus oxyrinchus	Shark, shortfin mako	X			unk[4]	unk[4]	J, A									
Sharks, cat	*Galeorhinus galeus*	Shark, soupfin (tope)	X			unk[2]	↓[6]	J, A									
Houndsharks	*Mustelus californicus*	Shark, gray smoothhound	X													J, A	J, A
	Mustelus henlei	Shark, brown smoothhound	X											A		A	J, A
	Triakis semifasciata	Shark, leopard	X			unk[5]	unk[5]								J, A	J, A	J, A
Sharks, requiem	*Prionace glauca*	Shark, blue	X			unk[2]	unk[2]	J, A									
Sharks, angel	*Squatina californica*	Shark, Pacific angel	X			unk[6]	↓[6]		J, A				A	J, A	A	J, A	J, A
Rays, torpedo electric	*Torpedo californica*	Ray, Pacific electric	X						J, A		J, A	J, A	J, A	J, A	J, A	J, A	J, A
Skates	*Raja binoculata*	Skate, big	X									J, A		J, A		J, A	J, A
	Raja inornata	Skate, California	X									J, A		J, A		J, A	J, A
	Raja rhina	Skate, longnose	X			66%[7]	NS		J, A		J, A	J, A	J, A	J, A	J, A	J, A	J, A

Taxonomic Group	Scientific Name	Common Name	Landed	E/T	At-Risk	Population Status		Habitat Categories									
						Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - Soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
Rays, eagle	*Myliobatis californica*	Ray, bat	X			unk[2]									A	J, A	J, A
Chimaeras, shortnose	*Hydrolagus colliei*	Ratfish, spotted	X						J, A		J, A	J, A	J, A	J, A	J, A	J, A	J, A
Sturgeons	*Acipenser medirostris*	Sturgeon, green[a]		T	SSC	unk[8]	unk[8]									J, A	J, A
Herrings	*Alosa sapidissima*	Shad, American	X					J, A									
	Clupea pallasii	Herring, Pacific	X			~28%[2,10]	↓[6]	J, A									J, A
	Sardinops sagax	Sardine, Pacific	X			~33%[9,10]	↑[9]	J, A									
Anchovies	*Engraulis mordax*	Anchovy, Northern	X			~25%[9,10]	NS[9]	J, A									J
Trouts and Salmons	*Oncorhynchus kisutch*	Salmon, coho[e]		E		~11%[12]		J, A									J, A
	Oncorhynchus mykiss irideus	Trout, steelhead[e]	X	T		~15%[12]		J, A									
	Oncorhynchus mykiss irideus	Trout, steelhead[f]	X	T		~5-15%[12]	NS or ↑[12]	J, A									
	Oncorhynchus tshawytscha	Salmon, chinook[b]	X		SSC, OF		NS or ↑[11]	J, A									J, A
	Oncorhynchus tshawytscha	Salmon, chinook[c]	X	T		~20-30%[12]	NS or ↑[12]	J, A									J, A
	Oncorhynchus tshawytscha	Salmon, chinook[d]	X	E		~10-14%[12]	NS or ↑[12]	J, A									J, A
Smelts	*Allosmerus elongatus*	Smelt, whitebait	X			unk[2]	unk[2]	J, A								J, A	J, A
	Hypomesus pretiosus	Smelt, surf	X			unk[2]	↓[6]	J, A									J, A
	Spirinchus starksi	Smelt, night	X			unk[2]	↓[6]	J, A									J, A
Lizardfishes	*Synodus lucioceps*	Lizardfish, California	X						J, A			J, A		J, A		J, A	J, A
Lancetfishes	*Alepisaurus ferox*	Lancetfish, longnose	X					J, A									
Cods	*Microgadus proximus*	Tomcod, Pacific	X									J, A		J, A		J, A	J, A
Grenadiers	*Coryphaenoides acrolepis*	Grenadier, Pacific	X			unk[6]	↓[6]	J, A				J, A					
Hakes, merlucciid	*Merluccius productus*	Hake, Pacific (whiting)	X			31-38%[7]	↑[7]	J, A	J, A		J, A	J, A	J, A	J, A	J, A	J, A	
Toadfishes	*Porichthys notatus*	Midshipman, plainfin	X						J, A			A	A	A	A	J, A	J, A
Sauries	*Cololabis saira*	Saury, Pacific	X					J, A									

Taxonomic Group	Scientific Name	Common Name	Landed	E/T	At-Risk	Population Status		Habitat Categories									
						Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - Soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
Silversides, New World	*Atherinops affinis*	Topsmelt	X			unk[2]		J, A									J, A
	Atherinopsis californiensis	Jacksmelt	X			unk[2]		J, A									J, A
Opahs	*Lampris guttatus*	Opah	X			unk[2,13]		J, A									
Rockfishes	*Sebastes atrovirens*	Rockfish, kelp	X			unk[2]	↓[6]								J, A		J, A
	Sebastes auriculatus	Rockfish, brown	X			unk[2]	↓[6]		J				J, A	J, A	J, A	J, A	J, A
	Sebastes aurora	Rockfish, aurora	X				↓[6]					J, A		J, A			
	Sebastes babcocki	Rockfish, redbanded	X				NS[6]				J, A	J, A	J, A	J, A	J, A	J, A	
	Sebastes carnatus	Rockfish, gopher	X			97%[7]	↓[7]								J, A		J, A
	Sebastes caurinus	Rockfish, copper	X			unk[2]	↓[6]						J, A	J	J, A	J	J, A
	Sebastes chlorostictus	Rockfish, greenspotted	X			31%[27]	↑[27]		J, A		A	A	A	A	J, A	J, A	
	Sebastes chrysomelas	Rockfish, black-and-yellow	X			unk[2]	↓[6]								J, A		J, A
	Sebastes constellatus	Rockfish, starry	X				↓[6]				J, A		J, A		J, A		J, A
	Sebastes crameri	Rockfish, darkblotched	X			30%[17]	↑[17]	J	J, A		A	A	J, A	J, A	J, A	J, A	
	Sebastes dallii	Rockfish, calico	X			unk[2]	unk[2]				J, A	J	J, A	J	J, A	J	J, A
	Sebastes diploproa	Rockfish, splitnose	X			66%[7]	↑[7]		J, A		A	J, A	A	J, A			
	Sebastes elongatus	Rockfish, greenstriped	X			81%[7]	↑[7]		J, A		J, A	J, A	J, A	J, A	J, A	J, A	J, A
	Sebastes ensifer	Rockfish, swordspine	X						J, A		A	J	A	J	A	J	
	Sebastes entomelas	Rockfish, widow	X			51%[19]	↑[19]	J, A			A		J, A		J, A		J
	Sebastes eos	Rockfish, pink	X				NS[6]		A		A	J	A	J	A	J	
	Sebastes flavidus	Rockfish, yellowtail	X			55%[7,13]	NS [7,13]	J, A	A		A		A		A		J, A
	Sebastes goodei	Rockfish, chilipepper	X			70%[7]	↑[7]	J, A	J, A		A		A		A	J	J, A
	Sebastes helvomaculatus	Rockfish, rosethorn	X				NS[6]		J, A		J, A	J	J, A	J			
	Sebastes hopkinsi	Rockfish, squarespot	X				NS[6]		J, A		J, A		J, A		J, A		J, A

Taxonomic Group	Scientific Name	Common Name	Landed	E/T	At-Risk	Population Status		Habitat Categories									
						Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - Soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
	Sebastes jordani	Rockfish, shortbelly	X			73%[7]	NS or ↑[7]	J, A	J, A		J, A		J, A		J, A		J
	Sebastes levis	Rockfish, cowcod	X		SSC, OF	5%[7,16]	↑[7,16]		J, A		A		J, A	J	J, A	J	
	Sebastes maliger	Rockfish, quillback	X			unk[2]	↓[6]				A		A		J, A		J, A
	Sebastes melanops	Rockfish, black	X			71%[7]	↑[7]	J, A			J, A		J, A		J, A		J, A
	Sebastes melanostomus	Rockfish, blackgill	X			30%[15]	↑[15]	J	A		A	A		J		J	
	Sebastes miniatus	Rockfish, vermilion	X			41-89%[18]	↑[18]		J, A		J, A	J	J, A	J	J, A	J	J, A
	Sebastes mystinus	Rockfish, blue	X			30%[7]	↑[7]	J			A		A		J, A	J	J, A
	Sebastes nebulosus	Rockfish, China	X			unk[2]	↓[6]						J, A		J, A		J, A
	Sebastes nigrocinctus	Rockfish, tiger	X				NS[6]				J, A		J, A		J, A		
	Sebastes ovalis	Rockfish, speckled	X				↓[6]		J, A		J, A		J, A		J, A		J, A
	Sebastes paucispinis	Rockfish, bocaccio	X		SSC	28%[7]	↑[7]	J, A	J, A		A		A		A		J, A
	Sebastes pinniger	Rockfish, canary	X		OF	23%[25]	↑[25]	J, A	J, A		A		J, A	J	J, A	J	J, A
	Sebastes proriger	Rockfish, redstripe	X						J, A		J, A		J, A				
	Sebastes rastrelliger	Rockfish, grass	X			unk[2]	↓[6]								J, A		J, A
	Sebastes rosaceus	Rockfish, rosy	X				↓[6]				J, A	J	J, A	J	J, A	J	J, A
	Sebastes rosenblatti	Rockfish, greenblotched	X				↓[6]		J, A		A	J, A	A	J, A	A	J, A	
	Sebastes ruberrimus	Rockfish, yelloweye	X		OF	21%[26]	↑[26]		J, A		J, A		J, A		J, A		
	Sebastes rubrivinctus	Rockfish, flag	X				↓[6]		J, A		J, A		J, A		J, A		
	Sebastes rufus	Rockfish, bank	X			25-31%[14]	↓[14]		J, A		J, A	J	J, A	J	J, A	J	
	Sebastes saxicola	Rockfish, stripetail	X				NS[6]		J, A		A	A	A	J, A	A	J, A	J
	Sebastes semicinctus	Rockfish, halfbanded	X						J, A		A	J, A	A	J, A	A	J, A	
	Sebastes serranoides	Rockfish, olive	X			unk[2]	↓[6]	J, A					J, A	J	J, A	J	J, A

Table 4

Taxonomic Group	Scientific Name	Common Name	Landed	E/T	At-Risk	Population Status		Habitat Categories									
						Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - Soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
	Sebastes serriceps	Rockfish, treefish	X			unk[2]	↑[6]								J, A		J, A
	Sebastes zacentrus	Rockfish, sharpchin	X				NS[6]				J, A		J, A		J, A		
Thornyheads	*Sebastolobus alascanus*	Thornyhead, shortspine	X		EN	63%[7]	NS[7]		J, A		J, A	J, A	J, A	J, A	J, A	J, A	J, A
	Sebastolobus altivelis	Thornyhead, longspine	X			71%[7]	↓[7]				J, A	J, A					
Sablefishes	*Anoplopoma fimbria*	Sablefish	X			33%[20]	↓[20]		J, A			A		J, A		J	J
Greenlings	*Hexagrammos decagrammus*	Greenling, kelp	X			49%[7]							J, A		J, A		J, A
	Ophiodon elongatus	Lingcod	X			74%[7]	↑[7]		J, A		J, A	J, A	J, A	J, A	J, A	J, A	J, A
	Oxylebius pictus	Greenling, painted	X												J, A		J, A
Sculpins	*Hemilepidotus hemilepidotus*	Irish lord, red	X								J, A		J, A		J, A		J, A
	Hemilepidotus spinosus	Irish lord, brown	X												J, A		J, A
	Leptocottus armatus	Sculpin, Pacific staghorn	X													J, A	J, A
	Scorpaenichthys marmoratus	Cabezon	X			45%[21]	↑[21]								A		J, A
Basses, striped	*Morone saxatilis*	Bass, striped	X			~33%[2]		J, A									J, A
Basses, sea and groupers	*Paralabrax clathratus*	Bass, kelp	X												J, A		J, A
Tilefishes	*Caulolatilus princeps*	Whitefish, ocean	X												J, A		J, A
Jacks	*Seriola lalandi*	Jack, yellowtail	X			unk[2,13]		J, A									
	Trachurus symmetricus	Mackerel, jack	X			unk[6,13]	NS[6]	J, A							J		J
Croakers and Drums	*Atractoscion nobilis*	Seabass, white	X			unk[5]	unk[5]	A					J, A	J	J, A	J	J, A
	Genyonemus lineatus	Croaker, white	X			unk[2]		J, A						J, A		J, A	J, A
Surfperches	*Amphistichus argenteus*	Surfperch, barred	X			unk[2]	↓[6]								J, A	J, A	J, A
	Brachyistius frenatus	Perch, kelp	X												J, A		J, A
	Cymatogaster aggregata	Perch, shiner	X										J, A	J, A	J, A	J, A	J, A

Taxonomic Group	Scientific Name	Common Name	Landed	E/T	At-Risk	Population Status		Habitat Categories									
						Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - Soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
	Embiotoca jacksoni	Perch, black	X												J, A		J, A
	Embiotoca lateralis	Seaperch, striped	X			unk[2]	NS or ↓[6]								J, A		J, A
	Hyperprosopon argenteum	Surfperch, walleye	X			unk[2]	↓[6]						J, A	J, A	J, A	J, A	J, A
	Hyperprosopon anale	Surfperch, spotfin	X													J, A	J, A
	Hyperprosopon ellipticum	Surfperch, silver	X												J, A	J, A	J, A
	Hypsurus caryi	Seaperch, rainbow	X												J, A		J, A
	Phanerodon atripes	Seaperch, sharpnose	X								J, A		J, A		J, A		J, A
	Phanerodon furcatus	Seaperch, white	X												J, A	J, A	J, A
	Rhacochilus toxotes	Seaperch, rubberlip	X			unk[2]	↓[6]								J, A	J, A	J, A
	Rhacochilus vacca	Perch, pile	X												J, A	J, A	J, A
Damselfishes	*Chromis punctipinnis*	Blacksmith	X												J, A		J, A
Wrasses	*Oxyjulis californica*	Senorita	X					A							J, A		J, A
	Semicossyphus pulcher	Sheephead, California	X			unk[2]	↑[6]								J, A		J, A
Clinids	*Heterostichus rostratus*	Kelpfish, giant	X												J, A		J, A
	Gibbonsia metzi	Kelpfish, striped	X														J, A
	Neoclinus blanchardi	Fringehead, sarcastic	X												J, A		J, A
Sandfishes	*Trichodon trichodon*	Sandfish, Pacific	X									J, A		J, A		J, A	J, A
Wolffishes	*Anarrhichthys ocellatus*	Wolf-eel	X				NS[6]	J			A		A		A		A
Sand Lances	*Ammodytes hexapterus*	Sand lance, Pacific	X													J, A	J, A
Gobies	*Lepidogobius lepidus*	Goby, bay	X													J, A	J, A
	Lythrypnus zebra	Goby, zebra	X												J, A		J, A
Barracudas	*Sphyraena argentea*	Barracuda, Pacific	X			unk[6,13]	NS[6]	J, A									

Taxonomic Group	Scientific Name	Common Name	Landed	E/T	At-Risk	Population Status		Habitat Categories									
						Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - Soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
Mackerels	*Katsuwonus pelamis*	Tuna, skipjack	X			unk[4]	unk[4]	J, A									
	Sarda chiliensis	Bonito, Pacific	X			unk[1]	unk[1]	J, A									
	Scomber japonicus	Mackerel, Pacific chub	X			~21%[9]	↑[9]	J, A									
	Thunnus alalunga	Tuna, albacore	X			47%[4]	NS[4]	J, A									
	Thunnus albacares	Tuna, yellowfin	X			~28[4]	NS[4]	J, A									
	Thunnus obesus	Tuna, bigeye	X		VU	24%[4]	↑[4]	J, A									
	Thunnus thynnus	Tuna, bluefin	X			40-60%[4]	↓[4]	J, A									
Louvars	*Luvarus imperialis*	Louvar	X			unk[2,13]	unk[2]	J, A									
Butterfishes	*Peprilus simillimus*	Pompano, Pacific	X					J, A								J, A	J, A
Flounders, sand	*Citharichthys sordidus*	Sanddab, Pacific	X			unk[6]	NS[6]					J, A		J, A		J, A	J, A
	Citharichthys stigmaeus	Sanddab, speckled	X			unk[6]	NS[6]									J, A	J, A
	Citharichthys xanthostigma	Sanddab, longfin	X			unk[6]	NS[6]							J, A		J, A	J, A
	Hippoglossina stomata	Sole, bigmouth	X									J, A		J, A		J, A	J, A
	Paralichthys californicus	Halibut, California	X			unk[22]	unk[22]							J, A		J, A	J, A
	Xystreurys liolepis	Sole, fantail	X													J, A	J, A
Flounders, righteye	*Atheresthes stomias*	Flounder, arrowtooth	X			79%[7]						A		J, A		J	J
	Eopsetta jordani	Sole, petrale	X			18%[24]	NS[24]		J, A			A		J, A		J, A	J, A
	Glyptocephalus zachirus	Sole, rex	X			unk[6]	↓[6]		J, A			J, A		J, A		J, A	J, A
	Hippoglossus stenolepis	Halibut, Pacific	X										A	A	J, A	J, A	J, A
	Isopsetta isolepis	Sole, butter	X									A		A		J, A	J, A
	Lepidopsetta bilineata	Sole, rock	X			unk[6]	NS[6]				J, A	J, A	J, A	J, A	J, A	J, A	J, A
	Lyopsetta exilis	Sole, slender										J, A		J, A		J, A	J, A
	Microstomus pacificus	Sole, Dover	X			84%[23]	↓[23]		J, A			A		J		J	J
	Parophrys vetulus	Sole, English	X			116%[7]	↑[7]		A			A		A		J, A	J, A

Taxonomic Group	Scientific Name	Common Name	Landed	E/T	At-Risk	Population Status		Habitat Categories									
						Relative Biomass	Recent Trend	Open Water	Can-yon	Rise - Soft	Slope - Hard	Slope - Soft	Shelf II - Hard	Shelf II - Soft	Shelf I - Hard	Shelf I - Soft	Near-shore
	Platichthys stellatus	Flounder, starry	X			62%[7]	↓[7]							A		J, A	J, A
	Pleuronichthys coenosus	Sole, C-O	X								J, A	J, A	J, A	J, A	J, A	J, A	J, A
	Pleuronichthys decurrens	Sole, curlfin	X									J, A		J, A		J, A	J, A
	Pleuronichthys guttulatus	Turbot, diamond	X													J, A	J, A
	Psettichthys melanostictus	Sole, sand	X			unk[2]	↓[6]					J, A		J, A		J, A	J, A
Molas	*Mola mola*	Sunfish, ocean	X					J, A									

[a] Southern DPS; [b] Sacramento River Fall/Late Fall ESU; [c] Central Valley Spring ESU; [d] Sacramento River Winter ESU; [e] Central California Coast ESU; [f] South/Central California Coast ESU.

[1] CDFG 2010b; [2] Leet et al. 2001; [3] Gertseva and Taylor 2011; [4] PFMC 2011; [5] CDFG 2008b; [6] Starr et al. 2002a; [7] PFMC & NMFS 2011; [8] NOAA Fisheries Office of Protected Resources 2012; [9] PFMC 2005; [10] population size strongly influenced by environmental conditions; [11] PFMC 2006;[12] PCSRF 2005; [13] abundance off central California increases during warm water events; [14] Piner et al. 2000; [15] Field and Pearson 2011 (draft); [16] assessed stock occurs outside the MBNMS; [17] Stephens et al. 2011; [18] MacCall 2005; [19] He et al. 2011; [20] Stewart et al. 2011; [21] Cope and Key 2009; [22] CDFG 2004; [23] Hicks and Wetzel 2011 (draft); [24] Haltuch et al. 2011; [25] Wallace and Cope 2011; [26] Taylor and Wetzel 2011 (draft); [27] Dick et al. 2011; [28] http://www.nmfs.noaa.gov/pr/species/fish/baskingshark.htm

Table 5. Reptile species of special interest in MBNMS.
Reptile species in MBNMS that receive relatively greater interest and attention from resource managers, including Endangered and Threatened species (E/T), and other 'at risk' species (defined in Table 1). Habitat distribution is provided based on habitat categories as defined in Table 2. The current population size/biomass relative to the historically high population size/biomass and the recent trend in population size are included; decreasing (↓). Population status information in red ink denotes information that is more than 5 years old (pre-2007). CR = Critically Endangered.

Taxonomic Group	Scientific Name	Common Name	E/T	At-Risk	Population Status		Habitat Categories						
					Relative Biomass	Recent Trend	Open Water	Can-yons	Rise	Slope	Shelf II	Shelf I	Near-shore
Sea Turtle	*Dermochelys coriacea*	Turtle, Leatherback	E	CR	<30% [1]	↓[1]	X	X					

[1]Reviewed in CEC 2005

Table 6. Seabird species of special interest in MBNMS.
Searbid species in MBNMS that receive relatively greater interest and attention from resource managers, including Endangered and Threatened species (E/T), and other 'at risk' species (defined in Table 1). Only species that occur in offshore habitats in MBNMS were included. Habitat distribution is provided based on habitat categories as defined in Table 2. When available, the current population size/biomass relative to the historically high population size/biomass and the recent trend in population size are included; increasing (↑), decreasing (↓), trend not significant (NS), or unknown (unk). Population status information in red ink denotes information that is more than 5 years old (pre-2007). SSC = Species of Concern; VU = Vulnerable; EN = Endangered.

Taxonomic Group	Scientific Name	Common Name	E/T	At-Risk	Population Status		Habitat Categories						
					Relative Biomass	Recent Trend	Open Water	Can-yon	Rise	Slope	Shelf II	Shelf I	Near-shore
Loons	*Gavia* spp	Loons (Pacific, Red-necked)			>40% [2]	unk[1]	X						X
Grebes	*Aechmophorus* spp	Grebes (Clark's, Western)			>40% [2]	unk[1]	X						X
Albatrosses	*Phoebastria albatrus*	Albatross, Short-tailed	E	SSC, VU	low [3]	↑[3]	X	X					
	Phoebastria immutabilis	Albatross, Laysan			reduced [3]	NS or ↓[3]	X	X					
	Phoebastria nigripes	Albatross, Black-footed		VU	reduced [3]	↓[3]	X	X					
Shearwaters, Petrels	*Fulmarus glacialis*	Fulmar, Northern			>40% [2]	↑[1]	X	X					
	Puffinus bulleri	Shearwater, Buller's		VU		unk[1]	X	X					
	Puffinus creatopus	Shearwater, Pink-footed		VU		NS [1]	X	X				X	
	Puffinus griseus	Shearwater, Sooty			>40% [2]	↓[1]	X	X				X	X
	Puffinus opisthomelas	Shearwater, Black-vented			>40% [2]	NS [1]	X	X				X	X
Storm-Petrels	*Oceanodroma furcata*	Storm-Petrel, Fork-tailed		SSC	unk [3]	↓[3]	X	X					
	Oceanodroma homochroa	Storm-Petrel, Ashy		SSC, EN	unk [3]	NS or ↓[3]	X	X					
	Oceanodroma melania	Storm-Petrel, Black		SSC	unk [3]	maybe ↓[3]	X	X					

Taxonomic Group	Scientific Name	Common Name	E/T	At-Risk	Population Status		Habitat Categories						
					Relative Biomass	Recent Trend	Open Water	Can-yon	Rise	Slope	Shelf II	Shelf I	Near-shore
Pelicans	*Pelecanus occidentalis californicus*	Pelican, California Brown			high [3]	NS or ↑ [3]	X						X
Cormorants	*Phalacrocorax pelagicus*	Cormorant, Pelagic			high [3]	NS [3]	X						X
	Phalacrocorax penicillatus	Cormorant, Brandt's			<75% [3]	NS or ↓ [3]	X					X	X
Phalaropes	*Phalaropus lobatus*	Phalarope, Red-necked			>40% [2]	NS [1]	X	X					
Auks	*Brachyramphus marmoratus marmoratus*	Murrelet, Marbled	E	EN	<8% [4]	NS [4]	X	X					X
	Cepphus columba	Guillemot, Pigeon			high [3]	NS or ↑ [3]	X					X	X
	Cerorhinca monocerata	Auklet, Rhinoceros			reduced [3]	↑ [3,5]	X	X				X	
	Fratercula cirrhata	Puffin, Tufted		SSC	reduced [3]	↓ [3]	X	X					
	Ptychoramphus aleuticus	Auklet, Cassin's		SSC	reduced [3]	↓ [3]	X	X					
	Synthliboramphus hypoleucus	Murrelet, Xantus's	T	VU	<50-70% [3]	↓ [3]	X	X					
	Uria aalge	Murre, Common			<50% [3,5]	↑ [3,5]	X				X	X	X

[1] Recent population trend based on analysis of shipboard survey data sets from 1985-2001 as published in NCCOS 2003; [2] Appendix G in CDFG 2008a; [3]USFWS 2005; [4] central California population, McShane et al. 2004; [5] central California breeding population

Table 7. Marine mammal species of special interest in MBNMS.

Marine mammal species in MBNMS that receive relatively greater interest and attention from resource managers, including Endangered and Threatened species (E/T), and other ‘at risk’ species (defined in Table 1). Only species that occur in offshore habitats in MBNMS were included. Habitat distribution is provided based on habitat categories as defined in Table 2. When available, the current population size/biomass relative to the historically high population size/biomass and the recent trend in population size are included; increasing (↑), decreasing (↓), trend not significant (NS), or unknown (unk). Population status information in red ink denotes information that is more than 5 years old (pre-2007). SSC = Species of Concern; VU = Vulnerable; EN = Endangered.

Taxonomic Group	Scientific Name	Common Name	E/T	At-Risk	Population Status		Habitat Categories						
					Relative Biomass	Recent Trend	Open Water	Can-yons	Rise	Slope	Shelf II	Shelf I	Near-shore
Baleen Whales	*Eschrichtius robustus*	Whale, Gray			high [1,3]	NS or ↑[1]	X				X	X	X
	Megaptera novaeangliae	Whale, Humpback	E		unk [1,4]	↑[1,2]	X	X					
	Balaenoptera musculus	Whale, Blue	E	EN	unk [1,4]	NS [1,2]	X	X					
	Balaenoptera physalus	Whale, Fin	E	EN	unk [1,4]	↑[10]	X	X					
	Balaenoptera borealis	Whale, Sei	E	EN	unk [1]	unk [1,2]	X	X					
	Eubalaena japonica	Whale, North Pacific Right	E	EN	<1% [1]	unk [1]	X						
Toothed Whales	*Physeter macrocephalus*	Whale, Sperm	E	VU	unk [1,4]	unk [1,2]	X	X		X			
Dolphins	*Orcinus orca*	Whale, Killer [c]	E		~ 43% [1]	NS[1]	X	X					
Porpoises	*Phocoena phocoena*	Porpoise, Harbor [d]			unk [1,4]	NS[1]	X				X	X	X
	Phocoena phocoena	Porpoise, Harbor [e]			unk [1,4]	NS[1]	X				X	X	X
	Phocoena phocoena	Porpoise, Harbor [f]			unk [1,4]	↑[1]	X				X	X	X
Seals	*Phoca vitulina*	Seal, Harbor [a]			high [1,3]	NS [1]	X				X	X	X
	Mirounga angustirostris	Seal, Northern Elephant			high [1,3]	↑[1]	X	X		X	X	X	

Taxonomic Group	Scientific Name	Common Name	E/T	At-Risk	Population Status		Habitat Categories						
					Relative Biomass	Recent Trend	Open Water	Can-yons	Rise	Slope	Shelf II	Shelf I	Near-shore
Sea Lions, Fur Seals	*Callorhinus ursinus*	Fur Seal, Northern		VU	N/A[7]	↑[1]	X	X					
	Eumetopias jubatus	Sea Lion, Steller[b]	T	EN	<50% [1,6]	NS [1,6]	X			X	X	X	
	Arctocephalus townsendi	Fur Seal, Guadalupe	T	VU	unk [1]	↑[1]	X	X					
	Zalophus californicus	Sea Lion, California			high [1,3]	↑[1]	X	X			X	X	X
Sea Otters	*Enhydra lutris nereis*	Sea Otter, Southern	T	EN	~17% [8,9]	NS or ↓ [8]	X					X	X

[a] California Stock; [b] Eastern Stock; [c] Eastern North Pacific Southern Resident Stock; [d] San Francisco-Russian River stock; [e] Monterey Bay stock; [f] Morro Bay stock;

[1] NOAA Fisheries OPR Marine Mammals Stock Assessment Reports by Species/Stock website http://www.nmfs.noaa.gov/pr/sars/species.htm accessed in June 2012; [2] based on estimates for the stock off the U.S. west coast; [3] population may be approaching carrying capacity; [4] historic population size unknown; [5] Appendix G in CDFG 2008a; [6] for the population in central California only; [7] colony on San Miguel Island established in late 1960s; [8] Tinker et al. 2006; [9] USGS Western Ecological Research Center California Sea Otter Survey Results website http://www.werc.usgs.gov/ProjectSubWebPage.aspx?SubWebPageID=16&ProjectID=91 accessed in June 2012; [10] Moore and Barlow 2011

Table 8. The relative abundance of megafaunal invertebrates at three sites on the shelf.
Relative abundance of megafaunal invertebrates at Portuguese Ledge, Point Sur, and Big Creek was calculated based on surveys from a manned submersible (Graiff 2008). A mix of benthic habitats, ranging from high-relief rock to soft sediment, were surveyed at each site.

Phylum	Taxa	Common Name	% Observations		
			Portuguese Ledge	Point Sur	Big Creek
Annelida	*Serpula* spp.	tubeworm		<0.01	0.11
Arthropoda	*Lopholithodes foraminatus*	crab, brown box			<0.01
	Cancer spp.	crab, Cancer			<0.01
	Loxorhynchus crispatus	crab, decorator	<0.01	0.05	<0.01
	hermit crab	crab, hermit			0.07
	unknown crab spp.	crab, unknown			0.02
	Munida quadrispina	lobster, squat			9.75
	Pandalus platyceros	prawn, California spot	0.04		11.43
Brachiopoda	*Laqueus californicus*	brachiopod	41.76	22.35	
Bryozoa	*Heteropora pacifica*	bryozoan, northern staghorn			2.11
Chordata	*Urochordata* spp.	tunicates			0.03
Cnidaria	*Anthopleura* spp.	anemone, *Anthopleura* spp.			<0.01
	Urticina piscivora	anemone, fish eating			1.84
	Metridium farcimen	anemone, giant white-plumed	1.29	0.02	4.69
	Stomphia coccinea	anemone, swimming	0.34	<0.01	0.4
	unknown anemone	anemone, unknown	0.04		<0.01
	unknown sand anemone	anemone, unknown sand			0.83
	Urticina spp.	anemone, *Urticina* spp.		<0.01	0.8
	unknown coral	coral, unknown			0.02
	Gorgonacea	sea fan/sea whip	1.5	0.23	0.43
	sea fan	sea fan	0.04	0.02	
	Ptilosarcus gurneyi	sea pen, fleshy	0.1		0.17
	Subselliflorae sea pen	sea pen, Subselliflorae spp.	5.13	0.5	10.91
Echinodermata	*Gorgonocephalus eucnemis*	basket star	0.24		0.07
	Ophiuridae	brittle stars	14.86	<0.01	4.94
	Florometra serratissima	feather star	18.87	65.1	8.6
	Parastichopus spp.	sea cucumber, *Parastichopus* spp.			0.45
	Parastichopus californicus	sea cucumber, California	0.88		0.06
	Patiria miniata	sea star, bat	0.03		21.69
	Patiria miniata/Mediaster aequalis	sea star, bat/vermillion			2.54
	Mediaster aequalis	sea star, vermillion	12.95	2.6	7.18
	Ceramaster patagonicus	sea star, cookie	0.02	0.86	0.3
	Pteraster tesselatus	sea star, cushion	<0.01	0.01	
	Stylasterias forreri	sea star, fish eating	0.22		0.37
	Stylasterias forreri/Orthasterias koehleri	sea star			<0.01
	Linckia columbiae?	sea star, fragile		<0.01	
	Henricia spp.	sea star, Henricia spp.	0.06	0.04	0.76
	Dermasterias imbricata	sea star, leather			<0.01

Phylum	Taxa	Common Name	% Observations		
			Portuguese Ledge	Point Sur	Big Creek
	Leptasterias spp.	sea star, *Leptasterias* spp.			0.08
	Pisaster spp.	sea star, *Pisaster* spp.			0.17
	Pycnopodia/Rathbunaster	sea star, *Pycnopodia/Rathbunaster*	0.85	<0.01	0.85
	Orthasterias koehleri	sea star, redbanded			0.25
	Luidia foliolata	sea star, sand/mud	0.33	0.09	0.38
	Pisaster brevispinus	sea star, short-spinned			0.38
	unknown sea star	sea star, unknown	0.05	0.03	0.1
	Pteraster militaris	sea star, wrinkled	<0.01	0.03	0.1
	Lytechinus pictus	urchin, white sea		2.65	
Mollusca	*Dorididae* spp.	dorids			<0.01
	Octopus spp.	octopus			0.08
	Pleurobranchea californica	sea slug, California		<0.01	
Porifera	barrel sponge	sponge, barrel	0.14	0.76	0.57
	branching sponge	sponge, branching		0.07	
	flat sponge	sponge, flat	0.05	3.5	2.76
	foliose sponge	sponge, foliose	0.12	0.96	3.25
	mound sponge	sponge, mound	<0.01	<0.01	0.26
	vase sponge	sponge, vase	0.03	0.09	0.09

Table 9. Summary of baseline characterization data for eight marine protected areas.

Summary of data collected by Starr and Yoklavich (2008) in the deep portions of eight Marine Life Protection Act marine protected areas (no shading) and associated reference sites (grey shading) that are located inside MBNMS. A manned submersible was used to survey benthic habitat, megafaunal invertebrates, and fishes from 24–365 m deep in Monterey Bay and along the Big Sur coast. Ranks of relative abundance of fish groups based on pie chart diagrams in Starr and Yoklavich (2008). SMCA = State Marine Conservation Area; SMR = State Marine Reserve; RF = rockfish; YOY = Young-of-the-Year; U = Unknown

***Habitat Category*/ Site Name**	**Benthic Habitat Surveyed (% of total area)**	**Dominant Megafaunal Invertebrates (% total counted)**	**Mean Density (fishes/ 100 m²)**	**Relative Abundance of Fishes by Groups** rank 1		**rank 2**		**rank 3**		**rank 4**		**rank 5**		**rank 6**		**rank 7**		**rank 8**		**rank 9**
Shelf I (<100 m)																				
Soquel Canyon SMCA (inside)	55% = high-relief rock, mud, cobble mixtures; 45% = low-relief mud, mud-rock, mud-cobble	79% = feather stars, brittlestars, sea stars, nipple sponges	45.6	Fished RF	>	Other RF	>	Dwarf RF	>	Flatfish	≈	Other	>	Sea Perches	>	U				
Portuguese Ledge SMCA (inside)	51% = mud habitats; 38% rock ridges, rock-mud, rock-boulder, rock-cobble	83% = sea stars, feather stars, corals, brittlestars	50.3	Dwarf RF	>	Fished RF	>	Other	>	Other RF	≈	YOY RF	>	Rays	≈	Sea Perches	>	Flatfish	≈	U
Portuguese Ledge SMCA (reference)	47% = rock-ridge, rock-cobble, rock-boulder, rock-mud; 37% = mud	50% = brachiopods, feather stars; sea stars, brittlestars, sea whip corals also common	66.1	Dwarf RF	>	YOY RF	>	Fished RF	>	Other	>	Other RF	>	Rays	≈	Sea Perches	≈	Flatfish	≈	U
Point Lobos SMR (inside)	96% = rock, boulder, cobble	94% = sea stars, corals, brittlestars, sponges	56	Dwarf RF	>	Other	≈	Fished RF	>	YOY RF	≈	Other RF	>	Rays	≈	Sea Perches	≈	Flatfish	≈	U
Point Lobos SMR (reference)	92% = rock, cobble, boulder	62% = sea stars; sea whip corals, hydrocorals also abundant	48	YOY RF	≈	Other	≈	Dwarf RF	≈	Fished RF	>	Other RF	>	U	>	Sea Perches				
Point Lobos SMCA (inside)	37% = cobble; 33% = rock; 21% = mud, mud-pebble, mud-rock	93% = brachiopods, feather stars, brittlestars	69.3	Dwarf RF	>	Fished RF	>	Flatfish	≈	Other RF	>	Other	≈	YOY RF	≈	Rays	≈	Sea Perches	≈	U
Point Lobos SMCA (reference)	70% = rock, cobble, boulders; 27% = mud, mud-cobble, mud-rock	Brittlestars, feather stars, sea stars	48	YOY RF	≈	Other	≈	Dwarf RF	≈	Fished RF	>	Other RF	>	U	>	Sea Perches				
Point Sur SMR (inside)	91% = rock-ridge, rock-sand, rock-cobble	97% = bat sea stars, red gorgonian corals, hydrocorals, nipple sponges	12.5	Other	>	Fished RF	>	Other RF	>	YOY RF	>	Flatfish	≈	Sea Perches	≈	U	≈	Dwarf RF		
Point Sur SMR (reference)	95% = rock	Sea stars, sponges, sea whip corals, hydrocorals	20.5	Fished RF	>	Other	>	YOY RF	>	Other RF	≈	Sea Perches	>	U						
Point Sur SMCA (inside)	80% = rock, boulder, cobble; 16% = mud, mud-boulder, mud-cobble, mud-rock	83% = brachiopods; sea stars, sea whip corals, feather stars also common	64.7	YOY RF	>	Other	≈	Dwarf RF	≈	Fished RF	>	Other RF	>	Rays	≈	Sea Perches	≈	Flatfish	≈	U

Habitat Category/ Site Name	Benthic Habitat Surveyed (% of total area)	Dominant Megafaunal Invertebrates (% total counted)	Mean Density (fishes/ 100 m^2)	Relative Abundance of Fishes by Groups rank 1		rank 2		rank 3		rank 4		rank 5		rank 6		rank 7		rank 8		rank 9
Point Sur SMCA (reference)	90% = mixtures of rock and boulder habitats	~97% = sea stars, red gorgonian corals, feather stars, barrel sponges, brachiopods	91.9	YOY RF	>	Fished RF	≈	Dwarf RF	>	Other	>	Other RF	>	Sea Perches	≈	Flatfish	≈	U		
Big Creek SMR (inside)	50% = complex rock habitats; 50% low-relief sand and mud	73% = sea stars, sponges, brittlestars	32.5	Fished RF	>	Other	>	YOY RF	>	Flatfish	>	Dwarf RF	>	Sea Perches	≈	Other RF	≈	U		
Big Creek SMR (reference)	39% = rock; 30% = mud; 28% = sand	66% = brachiopods, sea stars, sponges	17	Fished RF	>	Other	>	YOY RF	>	Flatfish	>	Other RF	≈	Sea Perches	≈	U				
Shelf II (100-200 m)																				
Soquel Canyon SMCA (inside)	55% = high-relief rock, mud, cobble mixtures; 45% = low-relief mud, mud-rock, mud-cobble	Feather stars, brittlestars, sea stars, nipple sponges	22	Fished RF	>	Dwarf RF	≈	Flatfish	≈	Other	≈	Other RF	>	U	>	Rays	>	Sea Perch		
Soquel Canyon SMCA (reference)	58% = high-relief rock ridges, rock-mud slopes; 42%= mud, mud-cobble, mud-rock	81% = brachiopods, brittlestars, red sea stars	17	Fished RF	>	Other	>	Other RF	≈	Dwarf RF	≈	Flatfish	>	U	>	Rays	>	Sea Perch		
Portuguese Ledge SMCA (inside)	51% = mud habitats; 38% rock ridges, rock-mud, rock-boulder, rock-cobble	83% = sea stars, feather stars, corals, brittlestars	14.9	Dwarf RF	>	Flatfish	≈	Other	>	Other RF	>	Fished RF	>	U						
Portuguese Ledge SMCA (reference)	47% = rock-ridge, rock-cobble, rock-boulder, rock-mud; 37% = mud	50% = brachiopods, feather stars; red sea stars, brittlestars, sea whip corals also common	25.2	Dwarf RF	>	Fished RF	>	Other	>	Other RF	≈	Flatfish	>	YOY RF	≈	U	≈	Rays	≈	Sea Perch
Point Lobos SMCA (inside)	37% = cobble; 33% = rock; 21% = mud, mud-pebble, mud-rock	93% = brachiopods, feather stars, brittlestars	28.2	Dwarf RF	>	Fished RF	>	Other RF	>	Other	>	Flatfish	>	U						
Point Lobos SMCA (reference)	70% = rock, cobble, boulders; 27% = mud, mud-cobble, mud-rock	Brittlestars, feather stars, sea stars (especially batstars)	12.8	Fished RF	>	Dwarf RF	≈	Other RF	>	Other	≈	Flatfish	>	U						
Point Sur SMCA (inside)	80% = rock, boulder, cobble; 16% = mud, mud-boulder, mud-cobble, mud-rock	83% = brachiopods; sea stars, sea whip corals, feather stars also common	22.4	Fished RF	>	Dwarf RF	>	Other	>	Other RF	>	Flatfish								
Point Sur SMCA (reference)	90% = mixtures of rock and boulder habitats	Sea stars, red gorgonian corals, feather stars, brachiopods, barrel sponges	150.7	Dwarf RF	>	Fished RF	>	Other RF	>	YOY RF	≈	Other	>	U						
Big Creek SMR (inside)	50% = complex rock habitats; 50% low-relief sand and mud	73% = sea stars, sponges, brittlestars	47	Dwarf RF	>	Fished RF	>	Other RF	>	Other	>	Flatfish	>	U	≈	Sea Perch				

Habitat Category/ Site Name	Benthic Habitat Surveyed (% of total area)	Dominant Megafaunal Invertebrates (% total counted)	Mean Density (fishes/ 100 m^2)	Relative Abundance of Fishes by Groups rank 1		rank 2		rank 3		rank 4		rank 5		rank 6		rank 7		rank 8		rank 9
Big Creek SMR (reference)	39% = rock; 30% = mud; 28% = sand	66% = brachiopods, sea stars, sponges	35.4	Dwarf RF	>	Fished RF	≈	Other RF	>	Other	≈	Flatfish	>	Sea Perch	≈	YOY RF	≈	U	≈	Rays
Big Creek SMCA (inside)	58% = rock, boulder, cobble; 42% = mud, mud-rock, mud-cobble	81% = brittlestars, sea stars, shelf sponges	28.3	Fished RF	>	Other RF	>	Dwarf RF	>	Other	>	Flatfish	>	U						
Big Creek SMCA (reference)	55% = rock; 45% = mud	70% = brachiopods	25.3	Dwarf RF	>	Fished RF	>	Other RF	>	Flatfish	>	Other	>	YOY RF	≈	Rays				
Slope (>200 m)																				
Soquel Canyon SMCA (inside)	55% = high-relief rock, mud, cobble mixtures; 45% = low-relief mud, mud-rock, mud-cobble	Feather stars, brittlestars, sea stars, nipple sponges	17.6	Other	>	Fished RF	>	Flatfish	>	Other RF	≈	Dwarf RF	>	U	≈	Rays				
Soquel Canyon SMCA (reference)	58% = high-relief rock ridges, rock-mud slopes; 42%= mud, mud-cobble, mud-rock	81% = brachiopods, brittlestars, red sea stars	14.6	Fished RF	>	Flatfish	≈	Other	>	Other RF	≈	Dwarf RF	>	U	≈	Rays				
Portuguese Ledge SMCA (inside)	51% = mud habitats; 38% rock ridges, rock-mud, rock-boulder, rock-cobble	83% = sea stars, feather stars, corals, brittlestars	27.2	Fished RF	>	Other	≈	Other RF	>	Flatfish	>	Dwarf RF	>	Rays	>	U				
Portuguese Ledge SMCA (reference)	47% = rock-ridge, rock-cobble, rock-boulder, rock-mud; 37% = mud	50% = brachiopods, feather stars; red sea stars, brittlestars, sea whip corals also common	15.3	Fished RF	>	Other	≈	Flatfish	>	Other RF	>	Dwarf RF	>	U	≈	Rays				
Point Lobos SMCA (inside)	37% = cobble; 33% = rock; 21% = mud, mud-pebble, mud-rock	93% = brachiopods, feather stars, brittlestars	16.2	Fished RF	>	Other	>	Flatfish	>	Dwarf RF	≈	Other RF	>	U						
Point Lobos SMCA (reference)	70% = rock, cobble, boulders; 27% = mud, mud-cobble, mud-rock	Brittlestars, feather stars, sea stars (especially batstars)	13.4	Fished RF	>	Other	>	Flatfish	>	Other RF	>	Dwarf RF	>	U	≈	Rays				
Big Creek SMR (inside)	50% = complex rock habitats; 50% low-relief sand and mud	73% = sea stars sponges, brittlestars	12.6	Fished RF	>	Other	≈	Other RF	>	Flatfish	≈	Dwarf RF		Rays	≈	U				
Big Creek SMR (reference)	39% = rock; 30% = mud; 28% = sand	66% = brachiopods, sea stars, sponges	11.7	Other	>	Fished RF	≈	Other RF	≈	Flatfish	>	Dwarf RF	>	U						

Table 10. Typical rockfish assemblage in each of five habitat categories.
The typical rockfish assemblage in each of five habitat categories off central and northern California (modified from Love et al. 2002). Habitat categories determined by water depth. X = multiple life stages present; YOY = young-of-the-year is the most common life stage present; J = juvenile (sometimes including YOY) is the most common life stage present.

Common Name of Rockfish Species	Scientific Name	Intertidal	Nearshore (to 30 m)	Shelf I (30-100 m)	Shelf II (100-200 m)	Slope (> 200 m)
Aurora	*Sebastes aurora*					X
Bank	*S. rufus*				X	X
Black	*S. melanops*	YOY	X	X		
Blackgill	*S. melanostomus*					X
Black-and-yellow	*S. chrysomelas*		X			
Blue	*S. mystinus*	YOY	X	X		
Bocaccio	*S. paucispinis*		J	X	X	X
Brown	*S. auriculatus*		X	X		
Canary	*S. pinniger*	YOY	J	X	X	
Chilipepper	*S. goodei*		J	X	X	X
China	*S. nebulosus*		X	X		
Copper	*S. caurinus*		X	X		
Cowcod	*S. levis*			J	X	X
Darkblotched	*S. crameri*					X
Flag	*S. rubrivinctus*				X	
Gopher	*S. carnatus*		X			
Grass	*S. rastrelliger*	X	X			
Greenblotched	*S. rosenblatti*				X	X
Greenspotted	*S. chlorostictus*			J	X	
Greenstriped	*S. elongatus*			J	X	X

Common Name of Rockfish Species	Scientific Name	Intertidal	Nearshore (to 30 m)	Shelf I (30-100 m)	Shelf II (100-200 m)	Slope (> 200 m)
Halfbanded	*S. semicinctus*			X	X	
Kelp	*S. atrovirens*		X			
Olive	*S. serranoides*			X		
Pygmy	*S. wilsoni*			X	X	
Quillback	*S. maliger*			X		
Redbanded	*S. babcocki*				X	
Rosethorn	*S. helvomaculatus*				X	X
Rosy	*S. rosaceus*			X		
Sharpchin	*S. zacentrus*				X	X
Shortbelly	*S. jordani*		J		X	X
Speckled	*S. ovalis*		J	X	X	
Splitnose	*S. diploproa*				J	X
Squarespot	*S. hopkinsi*			X		
Starry	*S. constellatus*			X		
Stripetail	*S. saxicola*			J	X	
Vermilion	*S. miniatus*		X	X	X	
Widow	*S. entomelas*		J	J	X	
Yelloweye	*S. ruberrimus*			X	X	
Yellowtail	*S. flavidus*	YOY	J		X	
Longspine thornyhead	*Sebastolobus altivelis*					X
Shortspine thornyhead	*Sebastolobus alascanus*					X

Table 11. Fish species assemblages from "A Biogeographic Assessment of North/Central California" Assemblages (species that tend to be caught together) were determined from data collected using four different methods: CDFG fishery dependent recreational fishing trips targeting rockfish (hook and line), NMFS fishery independent benthic trawls on the shelf and slope, and NMFS fisheries independent trawls in midwater (NCCOS 2003). Assemblages were named according to the most influential species in each group (from the clustering analysis). Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species occurred in other assemblages with random sampling. Assemblages differed by depth and to some extent by sampling method. Bottom type was not provided as a descriptor of the different assemblages. Rocky bottom on the shelf was probably the habitat most frequently sampled in the CDFG recreational data set. Gently sloping soft bottom on the shelf and slope was probably most frequently sampled in NMFS trawl surveys (highly sloped rocky bottom was not sampled).

Assemblage Name	Sampling Method	Approximate Depth Range (m)	Common Names of Species in Assemblage
Gopher rockfish	CDF&G recreational	13-39	black rockfish, brown rockfish, china rockfish, gopher rockfish, cabezon, kelp greenling
Blue rockfish	CDF&G recreational	13-82	blue rockfish, olive rockfish
Yellowtail rockfish	CDF&G recreational	24-119	canary rockfish, rosy rockfish, starry rockfish, yellowtail rockfish, copper rockfish, vermillion rockfish, lingcod, *Pacific sanddab*
Bocaccio	CDF&G recreational	55-119	bocaccio, flag rockfish, speckled rockfish, widow rockfish, yelloweye rockfish
Greenspotted rockfish	CDF&G recreational	77-157	chilipepper rockfish, greenstriped rockfish, greenspotted rockfish
Pacific herring	NMFS shelf trawl	62-121	California market squid, American shad, Chinook salmon, curlfin sole, Dungeness crab, longspine combfish, northern anchovy, Pacific herring, Pacific pompano, white croaker, *Pacific electric ray*
Halfbanded rockfish	NMFS shelf trawl	74-112	*halfbanded rockfish, Pacific mackerel, jack mackerel, Pacific argentine*
Pacific sanddab	NMFS shelf trawl	62-194	Pacific sanddab, English sole, petrale sole, pink seaperch, plainfin midshipman, *lingcod*
Big skate	NMFS shelf trawl	62-194	*spiny dogfish, big skate, California skate*
Chilipepper rockfish	NMFS shelf trawl	82-320	bocaccio, chilipepper rockfish, greenstriped rockfish, greenspotted rockfish, shortbelly rockfish, cowcod, stripetail rockfish
Darkblotched rockfish	NMFS shelf trawl	216-379	bank rockfish, darkblotched rockfish, redbanded rockfish, splitnose rockfish
Blackgill rockfish	NMFS shelf trawl	277-463	lingcod, aurora rockfish, black eelpout, blackgill rockfish, blacktail snailfish, brown cat shark, filetail cat shark, *lanternfish*

Assemblage Name	Sampling Method	Approximate Depth Range (m)	Common Names of Species in Assemblage
Rex sole	NMFS shelf trawl	All depths (62-463)	rex sole, *slender sole, spotted cusk-eel*
Pacific hake	NMFS shelf trawl	All depths (62-463)	*Pacific hake, longnose skate, spotted ratfish*
Shortspine thornyhead	NMFS shelf trawl	All depths (71-463)	shortspine thornyhead, Bering skate, bigfin eelpout, Dover sole, sablefish
Stripetail rockfish	NMFS slope trawl	214-312	bocaccio, chilipepper rockfish, greenstriped rockfish, lingcod, darkblotched rockfish, English sole, petrale sole, sharpchin rockfish, shortbelly rockfish, spot prawn, stripetail rockfish, *rosethorn rockfish, slender sole, redbanded rockfish, Pacific electric ray*
Splitnose rockfish	NMFS slope trawl	214-649	Bering skate, bigfin eelpout, longnose skate, Pacific hake, rex sole, splitnose rockfish, spotted ratfish
Filetail catshark	NMFS slope trawl	364-649	*black eelpout, filetail cat shark, California grenadier, flapjack devilfish, Pacific glass shrimp*
Longspine thornyhead	NMFS slope trawl	662-1207	black skate, California slickhead, crimson pasiphaeid, deepsea sole, giant grenadier, grooved tanner crab, longspine thornyhead, Pacific flatnose, Pacific grenadier, snakehead eelpout, twoline eelpout
Pacific viperfish	NMFS slope trawl	1017-1207	black hagfish, deepsea skate, fangtooth, longfin dragonfish, Pacific blackdragon, Pacific viperfish, rhomboid squid, sawtooth eel, smooth grenadier, threadfin slickhead, vampire squid, *magistrate armhook squid*
Aurora rockfish	NMFS slope trawl	All depths (214-1063 m)	aurora rockfish, blackgill rockfish, Dover sole, spiny dogfish, bank rockfish
Sablefish	NMFS slope trawl	All depths (214-1207 m)	blacktail snailfish, brown catshark, sablefish, shortspine thornyhead
Pacific hake (juvenile)	NMFS midwater trawl	Shallowest depth	California smoothtongue, Deep-sea smelt, euphausiid, Myctophid, Pacific hake (juv), *slender barracudina*
Canary rockfish (juvenile)	NMFS midwater trawl	Intermediate depth	black rockfish (juv), blue rockfish (juv), bocaccio (juv), canary rockfish (juv), chilipepper rockfish (juv), pygmy rockfish (juv), shortbelly rockfish (juv), squarespot rockfish (juv), stripetail rockfish (juv), widow rockfish (juv), yellowtail rockfish (juv)
Medusafish	NMFS midwater trawl	Intermediate depth	*King-of-the-salmon, medusafish, rex sole (juv)*
Slender sole (juvenile)	NMFS midwater trawl	Intermediate depth	*Pacific tomcod (juv), slender sole (juv), sand sole (juv), slender sole (adult)*

Assemblage Name	Sampling Method	Approximate Depth Range (m)	Common Names of Species in Assemblage
Spiny dogfish	NMFS midwater trawl	Intermediate depth	Pacific hake (adult), spiny dogfish
Pacific sanddab (juvenile)	NMFS midwater trawl	Intermediate depth	*brown rockfish (juv), copper rockfish complex, dover sole (juv), Northern anchovy (larval), Pacific argentine (juv), Pacific sanddab (juv), speckled sanddab (juv)*
Market squid	NMFS midwater trawl	Deepest depth	*Lingcod (juv), market squid, Northern anchovy, Pacific butterfish, Pacific electric ray, Pacific sanddab, Pacific sardine, plainfin midshipman*

Table 12. Relative abundance and seasonal occurrence of sea turtles, seabirds, and marine mammals off central California.
The relative abundance and seasonal occurrence of sea turtles, seabirds, and marine mammals in eight pelagic zones off central California (Research Planning Inc. 2006). Figure 12 shows the location of each zone. - = rare or absent; x = secondary area of occurrence / present irregularly; xx = primary area of occurrence; xxx = primary area of occurrence and high densities (compared to other areas).

Common Name	Scientific Name	Zone 1 (0-100m)	Zone 2 (0-200m)	Zone 3 (0-200m)	Zone 4 (0-200m)	Zone 5 (0-200m)	Zone 6 (200-3000m)	Zone 7 (100-200m)	Zone 8 (>3000m)	Seasonal presence
Sea Turtles										
Leatherback Turtle	*Dermochelys coriacea*	xxx	xx	xx	x	x	x	x	x	May-Nov
Seabirds										
Pacific Loons	*Gavia pacifica*	xx	xx	xx	x	xx	-	x	-	Oct-May
other Loons	*Gavia* spp.	xx	xx	xx	x	x	-	x	-	Oct-May
Clark's and Western Grebes	*Aechmophorus* spp.	xx	xx	xx	x	xx	-	-	-	Sept-May
Horned and Eared Grebes	*Podiceps* spp.	x	x	x	x	x	-	-	-	Sept-May
Black-Footed Albatross	*Phoebastria nigripes*	-	-	-	x	-	xx	xx	x	Dec-Aug
Sooty Shearwater	*Puffinus griseus*	xx	xxx	xxx	x	xx	x	xx	-	March-Nov
Other Shearwaters	*Puffinus* spp.	x	x	x	x	xx	x	xx	-	Year-round
Ashy Storm-Petrel	*Oceanodroma homochroa*	-	-	-	-	-	xx	x	-	Year-round
other Storm Petrel	*Oceanodroma* spp.	-	-	-	-	-	xx	x	x	March–Nov
Brown Pelican	*Pelecanus occidentalis*	xx	xx	xx	x	xx	-	x	-	March-Dec
Cormorants	*Phalacrocorax* spp.	xx	xx	xx	xx	xx	-	xx	-	Year-round
Surf Scoter	*Melanitta perspicillata*	xx	xx	xx	x	xx	-	-	-	Sept–April
White-Winged Scoter	*Melanitta fusca*	xx	x	xx	x	xx	-	-	-	Oct–April
Phalaropes	*Phalaropus* spp.	x	x	x	-	x	xx	xx	x	Year-round

Common Name	Scientific Name	Zone 1 (0-100m)	Zone 2 (0-200m)	Zone 3 (0-200m)	Zone 4 (0-200m)	Zone 5 (0-200m)	Zone 6 (200-3000m)	Zone 7 (100-200m)	Zone 8 (>3000m)	Seasonal presence
Gulls (multiple species)	*Larus* spp.	xx	xx	xx	x	xx	x	xx	-	Year-round
Common Murre	*Uria aalge*	xx	xxx	xx	x	xx	x-xx	xxx	-	Year-round
Pigeon Guillemot	*Cepphus columba*	x	xx	xx	x	xx	-	xx	-	Feb–Sept
Marbled Murrelet	*Brachyramphus marmoratus*	xx	xx	x	x	x	-	-	-	Year-round
Xantus's Murrelet	*Synthliboramphus hypoleucus*	-	-	-	-	-	xx	x	-	July–Oct
Cassin's Auklet	*Ptychoramphus aleuticus*	x	xx	xx	-	xx	xx	xx	-	Year-round
Rhinoceros Auklet	*Cerorhinca monocerata*	xx	xx	xx	x	xx	x	xx	-	Year-round
other seabirds		x	x	x	x	x	x	x	x	Year-round
Marine Mammals										
Northern Right Whale	*Eubalaena japonica*	x	x	x	x	x	x	x	x	Mar-May
Humpback Whale	*Megaptera novaeangliae*	xx	xx	xx	xx	xx	xx	xx	x	Mar–Nov
Minke Whale	*Balaenoptera acutorostrata*	xx	x	xx	xx	x	x	xx	x	Year-round
Sei Whale	*Balaenoptera borealis*	-	-	-	-	-	x	-	x	Year-round
Fin Whale	*Balaenoptera physalus*	x	x	x	x	x	xx	x	xx	Year-round
Blue Whale	*Balaenoptera musculus*	x	x	xx	x	xx	xx	xx	x	June–Nov
Gray Whale	*Eschrichtius robustus*	xx	xx	xx	xx	xx	-	x	-	Nov-May
Sperm Whale	*Physeter macrocephalus*	-	-	-	-	-	x	-	x	Year-round
Pygmy and Dwarf Sperm Whale	*Kogia* spp.	-	-	-	-	-	x	-	x	Year-round
Cuvier's Beaked Whale	*Ziphius cavirostris*	-	-	-	-	-	x	-	x	Year-round

Common Name	Scientific Name	Zone 1 (0-100m)	Zone 2 (0-200m)	Zone 3 (0-200m)	Zone 4 (0-200m)	Zone 5 (0-200m)	Zone 6 (200-3000m)	Zone 7 (100-200m)	Zone 8 (>3000m)	Seasonal presence
Baird's Beaked Whale	*Berardius bairdii*	-	-	-	-	-	x	-	-	May-Oct
Mesoplodon Beaked Whale	*Mesoplodon* spp.	-	-	-	-	-	x	-	x	Year-round
Bottlenose Dolphin	*Tursiops truncatus*	x	xx	xx	x	xx	-	-	-	Year-round
Short-beaked Common Dolphin	*Delphinus delphis*	x	x	x	x	xx	xx	x	xx	Year-round
Long-beaked Common Dolphin	*Delphinus capensis*	x	x	x	x	xx	x	x	x	Year-round
Pacific White-sided Dolphin	*Lagenorhynchus obliquidens*	x	x	x	xx	x	xx	xx	x	Year-round
Northern Right Whale Dolphin	*Lissodelphis borealis*	-	-	x	x	x	xx	xx	x	Year-round
Risso's Dolphin	*Grampus griseus*	x	x	xx	xx	xx	xx	xx	x	Year-round
Killer Whale	*Orcinus orca*	x	x	x	x	x	x	x	x	Year-round
Short-finned Pilot Whale	*Globicephala macrorhynchus*	x	x	x	x	x	x	x	x	Year-round
Harbor Porpoise	*Phocoena phocoena*	xx	xx	xx	x	xx	-	x	-	Year-round
Dall's Porpoise	*Phocoenoides dalli*	x	xx	xx	xx	xx	x	xx	x	Year-round
Guadalupe Fur Seal	*Arctocephalus townsendi*	-	-	-	-	-	x	-	x	Year-round
Northern Fur Seal	*Callorhinus ursinus*	x	x	x	x	x	xx	x	xx	Year-round
California Sea Lion	*Zalophus californianus*	xx	xx	xx	xx	xx	x	xx	x	Year-round
Steller Sea Lion	*Eumetopias jubatus*	x	xx	x	x	-	x	xx	-	Year-round
Harbor Seal	*Phoca vitulina*	xx	xx	xx	x	x	x	xx	-	Year-round
Northern Elephant Seal	*Mirounga angustirostris*	xx	xx	x	xx	x	xx	xx	x	Year-round
Southern Sea Otter	*Enhydra lutris nereis*	x	xx	xx	xx	xx	-	-	-	Year-round

Table 12

Table 13. Fish species associated with soft-bottom habitats in central California.
(A) Ecologically important species in middle shelf (31-100 m) and outer shelf (100-200 m) habitats off North-Central California (Cape Mendocino to San Simeon) as determined by Allen (2006). 'Ecologically important' species were defined as frequently occurring within a depth zone and likely to play important ecological roles (generally with regard to feeding) in the soft-bottom community. (B) Common benthic and benthopelagic fishes on the upper slope (200-500 m), middle slope (500-2,000 m), lower slope (2,000-3,000 m) and rise (>3,000 m) off California, as identified by Allen (2006) and Neighbors and Wilson (2006).

		A		B			
Common Name	**Scientific Name**	**Middle Shelf** (31-100 m)	**Outer Shelf** (101-200 m)	**Upper Slope** (201-500 m)	**Middle Slope** (501-2000 m)	**Lower Slope** (2001-3000 m)	**Rise** (>3000 m)
Hagfish, Black	*Eptatretus deani*			X	X	X	
Ratfish, Spotted	*Hydrolagus colliei*		X	X			
Catshark, Brown	*Apriturus brunneus*			X			
Catshark, Longnose	*Apriturus kampae*			X	X		
Catshark, Filetail	*Parmaturus xaniurus*			X	X		
Dogfish, Combtooth	*Centroscyllium nigrum*			X	X		
Dogfish, Spiny	*Squalus suckleyi*	X	X				
Shark, Pacific sleeper	*Somniosus pacificus*				X		
Ray, Pacific electric	*Torpedo californica*		X				
Skate, Big	*Raja binoculata*	X	X				
Skate, Longnose	*Raja rhina*			X			
Skate, Deep-sea	*Bathyraja abyssicola*				X	X	
Skate, Black	*Bathyraja trachura*				X		
Slickhead, California	*Alepocephalus tenebrosus*			X	X		
Slickhead, Threadfin	*Talismania birfurcata*				X		
Lizardfish, Highfin	*Bathysaurus mollis*				X	X	X
Cuskeel	*Barathronus pacificus*						X
Cuskeel, Paperbone	*Lamprogrammus niger*				X		
Cuskeel, Pudgy	*Spectrunculus grandis*				X	X	X
Cuskeel, Spotted	*Chilara taylori*	X	X	X			
Codling, Pacific Flatnose	*Antimora microlepis*			X	X	X	X

Common Name	Scientific Name	A		B			
		Middle Shelf (31-100 m)	**Outer Shelf** (101-200 m)	**Upper Slope** (201-500 m)	**Middle Slope** (501-2000 m)	**Lower Slope** (2001-3000 m)	**Rise** (>3000 m)
Grenadier, Pacific	*Coryphaenoides acrolepis*				X	X	
Grenadier, Abyssal	*Coryphaenoides armatus*					X	X
Grenadier, Threadfin	*Coryphaenoides filifer*					X	
Grenadier, Ghostly	*Coryphaenoides leptolepis*					X	X
Grenadier, Giant	*Coryphaenoides pectoralis*				X	X	
Grenadier, Rough abyssal	*Coryphaenoides yaquinae*						X
Grenadier	*Echinomacrurus occidentalis*					??	X
Grenadier, Bluntnose	*Nezumia kensmithi*				X	??	
Grenadier, Smooth	*Nezumia liolepis*				X	X	
Grenadier, California	*Nezumia stelgidolepis*			X	X		
Whiting, Pacific (Hake)	*Merluccius productus*	X	X	X	X		
Midshipman, Plainfin	*Porichthys notatus*	X	X				
Rockfish, Copper	*Sebastes caurinus*	X					
Rockfish, Greenspotted	*Sebastes chlorostictus*		X				
Rockfish, Splitnose	*Sebastes diploproa*			X			
Rockfish, Stripetail	*Sebastes saxicola*	X	X				
Thornyhead, Shortspine	*Sebastolobus alascanus*			X	X		
Thornyhead, Longspine	*Sebastolobus altivelis*			X	X		
Sablefish	*Anoplopoma fimbria*			X	X	X	
Lingcod	*Ophiodon elongatus*	X	X				
Combfish, Longspine	*Zaniolepis latipinnis*	X					
Sculpin, Blob	*Psychrolutes phrictus*				X	X	
Sculpin, Roughback	*Chitonotus pugetensis*	X					
Sculpin, Slim	*Radulinus asprellus*	X					
Sculpin, Threadfin	*Icelinus filamentosus*		X				

Common Name	Scientific Name	A		B			
		Middle Shelf (31-100 m)	**Outer Shelf** (101-200 m)	**Upper Slope** (201-500 m)	**Middle Slope** (501-2000 m)	**Lower Slope** (2001-3000 m)	**Rise** (>3000 m)
Poacher, Blacktip	*Xeneretmus latifrons*		X				
Snailfish, Blackfinned	*Careproctus cypselurus*			X	X		
Snailfish, Smalldisk	*Careproctus gilberti*			X	X		
Snailfish, Blacktail	*Careproctus melanurus*			X	X	X	
Snailfish, Swellhead	*Paraliparis cephalus*				X		
Snailfish, Longnose	*Rhinoliparis barbulifer*				X		
Croaker, White	*Genyonemus lineatus*	X					
Seaperch, Pink	*Zalembius rosaceus*	X	X				
Eelpout, Two-line	*Bothrocara brunneum*			X	X		
Eelpout, Bigfin	*Lycodes cortezianus*			X			
Eelpout, Snakehead	*Lycodes crotalinus*			X	X		
Eelpout, Black	*Lycodes diapterus*			X	X		
Eelpout, Deepwater	*Lycodes endemoscotus*				X	X	
Eelpout, Blackbelly	*Lycodes pacificus*		X				
Eelpout, Black mouth	*Lycodapus fierasfer*			X	X		
Sanddab, Pacific	*Citharichthys sordidus*	X					
Sole, Deep-sea	*Embassichthys bathybius*			X	X		
Sole, Dover	*Microstomus pacificus*	X	X	X	X		
Sole, English	*Pleuronectes vetulus*	X					
Sole, Petrale	*Eopsetta jordani*	X	X	X			
Sole, Rex	*Glyptocephalus zachirus*	X	X	X			
Sole, Slender	*Lyopsetta exilis*		X	X			

Table 14. Epipelagic and mesopelagic organisms observed by MBARI in MBNMS.
The relative frequency of sightings of midwater organisms by MBARI scientists during ROV research dives in Monterey Canyon (data provided by the Robison Lab). An annotation was made each time an organism (or group of organisms of the same type) was observed during a dive. For each depth category (in meters), the percentage of the total number of annotations (averaged over the years 2000, 2001, 2002) was calculated for each type of organism. XXX = over 10% of the total annotations at a given depth; XX = between 5-10% of the total annotations; X = between 1-5% of the total annotations; - = less than 1% of the total annotations; o = none observed.

Scientific Name or Taxonomic Group	Group Name	0-99	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-1000
Foraminiferida	Forams	x	-	x	x	-	-	-	-	o	o
Mitrocoma cellularia	Hydromedusae	xxx	xx	xx	x	xx	xx	xx	xx	x	x
Aegina citrea	Narcomedusae	x	x	x	x	xx	xxx	xxx	xxx	xxx	xxx
Solmissus spp.	Narcomedusae	x	x	xx	xx	x	x	x	-	-	-
Siphonophorae	Siphonophores	xx	x	x	x	x	x	x	x	x	x
Apolemia uvaria	Siphonophore	-	-	-	-	x	x	x	xx	x	x
Nanomia bijuga	Siphonophore	xxx	xxx	xxx	xxx	xxx	xx	x	-	-	o
Calycophorae	Siphonophores	x	xx	xx	xx	xx	xx	xx	xx	xx	xx
Cydippida	Comb Jellies	xx	x	x	x	x	x	x	x	x	x
Lobata	Comb Jellies	xx	x	x	x	x	x	x	x	x	x
Bolinopsis spp.	Comb Jellies	xx	x	x	-	-	x	x	x	x	xx
Beroe spp.	Comb Jellies	x	x	x	-	x	x	x	x	-	-
Poeobius meseres	Polychaete Worm	x	-	-	x	xx	x	x	x	x	xx
Euphausiidae	Krill	x	xx	xx	x	-	-	-	-	-	o

Scientific Name or Taxonomic Group	**Group Name**	**0-99**	**100-199**	**200-299**	**300-399**	**400-499**	**500-599**	**600-699**	**700-799**	**800-899**	**900-1000**
Sergestes similis	Shrimp	x	x	x	xxx	xx	xx	x	-	-	-
Mysidae	Mysid Shrimp	-	-	-	-	-	x	xx	xx	xxx	xxx
Acanthamunnopsis spp.	Isopod	x	xx	xxx	-	-	-	-	-	-	-
Rathbunaster californicus	Sun Star (larvae)	o	xx	x	x	-	o	-	-	o	o
Salpida	Salp	xx	x	x	xx	xxx	xx	x	x	-	-
Doliolida	Tunicate	-	-	-	-	x	xx	xx	xxx	xxx	xxx
Appendicularia	Larvaceans	xx	x	xx	xx	xxx	xxx	xx	xx	xx	xx
Bathochordaeus spp.	Larvaceans	x	xx	x	-	-	-	-	o	o	o
Mesochordaeus erythrocephalus	Larvacean	-	-	-	x	x	-	-	-	o	-
Sinker	Larvacean House	x	x	x	x	xx	xx	xx	xx	xx	xx
Chaetognatha	Arrow Worm	x	xx	xx	xx	xx	x	x	x	x	xxx
Osteichthyes	Fish - Bony Fish	x	-	-	-	x	x	x	x	x	x
Myctophidae	Fish - Lanternfish	x	x	x	x	x	x	-	-	-	-
Merluccius productus	Fish - Pacific Hake	-	x	x	x	x	x	x	-	-	o
Leuroglossus stilbius	Fish - Smooth Tongue	-	-	-	-	x	xx	x	x	-	-

Table 15. Ichthyoplankton assemblage along the U.S. West Coast.
The prevailing ichthyoplankton assemblages along the U.S. West Coast during spring include a Coastal/Shelf assemblage, a Slope assemblage, and an Oceanic assemblage (Doyle et al. 2002). Taxa selected for the assemblage analysis were those that were commonly collected during the study (occurred in 5% or more of samples from one or more cruises). The Slope assemblage represents a transition between the Coastal/Shelf and Oceanic assemblages, containing some species from both.

Common Name	**Scientific Name**	**Coastal/ Shelf**	**Slope**	**Oceanic**
Smelts	Osmeridae	X		
Blacksmelt, Pacific	*Bathylagus pacificus*		X	X
Blacksmelt, Popeye	*Bathylagus ochotensis*		X	X
Argentine, Bluethroat	*Nansenia candid*		X	X
Viperfish, Pacific	*Chauliodus macouni*		X	X
Headlightfish, California	*Diaphus theta*		X	X
Flashlightfish, California	*Protomyctophum crockeri*		X	X
Flashlightfish, Northern	*Protomyctophum thompsoni*		X	X
Lampfish, Pinpoint	*Lampanyctus regalis*			X
Lampfish, Broadfin	*Lampanyctus ritteri*			X
Lampfish, Northern	*Stenobrachius leucopsarus*	X	X	X
Lanternfish, Blue	*Tarletonbeania crenularis*		X	X
Lanternfishes	*Lampanyctus* spp		X	X
Lanternfishes	Myctophidae		X	X
Tomcod, Pacific	*Microgadus proximus*	X		
Bigscales	Melamphaidae			X
Thornyheads	*Sebastolobus* spp		X	X
Rockfishes	*Sebastes* spp		X	X
Snailfishes	*Liparis* spp.	X	X	
Flounder, Starry	*Platichthys stellatus*	X		
Sanddab, Pacific	*Citharichthys sordidus*		X	X
Sole, Butter	*Isopsetta isolepis*	X		
Sole, Dover	*Microstomus pacificus*		X	
Sole, English	*Pleuronectes vetulus*	X		
Sole, Rex	*Glyptocephalus zachirus*	X	X	
Sole, Sand	*Psettichthys melanostictus*	X		
Sole, Slender	*Lyopsetta exilis*	X	X	

Table 16. Epipelagic, mesopelagic and bathypelagic fish assemblages in MBNMS.
General depth of occurrence of fish species found in the open water habitats of central California. Epipelagic species tend to be found within 200 m of the surface, mesopelagic species are associated with the middle layer of the open ocean (generally 200-1000 m) and bathypelagic species are associated with the deepest portion of the open ocean (usually deeper than >1000 m). Many mesopelagic species undergo diurnal vertical migration and, thus may also spend time in the epipelagic habitat. This list includes many of the fish species inhabiting the open water habitats of the MBNMS, but is not comprehensive (sources include Silver et al. 1996 and Allen and Cross 2006). Depth information from Love (1996), Miller and Lea (1972), Fishbase, and Allen and Cross (2006).

Common Name	**Scientific Name**	**Epi-pelagic** (<200 m)	**Mesopelagic** (200-1000 m)	**Bathy-pelagic** (>1000 m)
Shark, Basking	*Cetorhinus maximus*	x		
Shark, Bigeye Thresher	*Alopias superciliosus*	x		
Shark, Common Thresher	*Alopias vulpinus*	x		
Shark, Blue	*Prionace glauca*	x		
Shark, Megamouth	*Megachasma pelagios*	x	x	
Shark, Salmon	*Lamna ditropis*	x		
Shark, Shortfin Mako	*Isurus oxyrinchus*	x		
Shark, Soupfin	*Galeorhinus galeus*	x		
Shark, White	*Carcharodon carcharias*	x	x	
Dogfish, Spiny	*Squalus suckleyi*	x		
Ray, Bay	*Myliobatis californica*	x		
Ray, Pacific Electric	*Torpedo californica*	x	x	
Stingray, Pelagic	*Dasyatis violacea*	x		
Ratfish, Spotted	*Hydrolagus colliei*	x		
Herring, Pacific	*Clupea pallasi*	x		
Sardine, Pacific	*Sardinops sagax*	x		
Anchovy, Northern	*Engraulis mordax*	x		
Salmon, Chinook	*Oncorhynchus tshawytscha*	x		
Salmon, Coho	*Oncorhynchus kisutch*	x		
Lancetfish, Longnose	*Alepisaurus ferox*	x	x	
Blacksmelt, Snubnose	*Bathylagus wesethi*		x	
Blacksmelt, Pacific	*Bathylagus pacificus*		x	x
Smoothtongue, California	*Leuroglossus stilbius*	x	x	
Blacksmelt, Popeye	*Lipolagus ochotensis*		x	x
Blacksmelt, Robust	*Pseudobathylagus milleri*		x	x
Spookfish, Javelin	*Bathylychnops exilis*		x	
	Mentodus facilis		x	x
Tubeshoulder, Shining	*Sagamichthys abei*		x	
Bristlemouth, Benttooth	*Cyclothone acclinidens*		x	x
Bristlemouth, Tan	*Cyclothone pallida*		x	x
Bristlemouth, Showy	*Cyclothone signata*	x	x	

Common Name	**Scientific Name**	**Epi-pelagic** (<200 m)	**Mesopelagic** (200-1000 m)	**Bathy-pelagic** (>1000 m)
Argentine, Pacific	*Argentina sialis*	x	x	
Hatchetfish, Slender	*Argyropelecus affinis*		x	
Hatchetfish, Silver	*Argyropelecus lychnus*		x	
Hatchetfish, Silvery	*Argyropelecus sladeni*	x	x	
Bottlelights	*Danaphos oculatus*		x	
Hatchetfish, Diaphanous	*Sternoptyx diaphana*		x	
Blackchin, Pacific	*Scopelengys tristis*		x	x
Lightfish, Panama	*Vinciguerria lucetia*	x	x	
Barreleye, Pacific	*Macropinna microstoma*	x	x	
Spookfish, Brownsnout	*Dolichopteryx longipes*		x	
Dragonfish, Highfin	*Bathophilus flemingi*		x	
Dragonfish, Longfin	*Tactostoma macropus*		x	
Viperfish, Pacific	*Chauliodus macouni*		x	x
Blackdragon, Pacific	*Idiacanthus antrostomus*		x	
Loosejaw, Shining	*Aristostomias scintillans*		x	
Barracudina, Slender	*Lestidiops ringens*	x	x	x
Blackchin, Pacific	*Scopelengys tristis*		x	
Daggertooth, North Pacific	*Anotopterus nikparini*	x	x	x
Headlightfish, California	*Diaphus theta*	x	x	
Lanternfish, Longfin	*Diogenichthys atlanticus*	x	x	
Lampfish, Pinpoint	*Nannobrachium regale*	x	x	
Lampfish, Broadfin	*Nannobrachium ritteri*	x	x	
Flashlightfish, California	*Protomyctophum crockeri*	x	x	
Lampfish, Northern	*Stenobrachius leucopsarus*	x	x	x
Lanternfish, California	*Symbolophorus californiensis*	x	x	
Lanternfish, Blue	*Tarletonbeania crenularis*	x	x	
Flying Fish, California	*Cypselurus californicus*	x		
Whiting, Pacific (Hake)	*Merluccius productus*	x	x	
Saury, Pacific	*Cololabis saira*	x		
Oreo, Oxeye	*Allocyttus folletti*	x	x	
Opah	*Lampris guttatus*	x	x	
Dreamer, Spiny	*Oneirodes acanthias*		x	x
Bigscale, Crested	*Poromitra crassiceps*		x	x
Bigscale, Twospine	*Scopelogadus mizolepis bispinosus*		x	x
Fangtooth	*Anoplogaster cornuta*		x	x
Eelpout, Pallid	*Lycodapus mandibularis*	x	x	
Eelpout, Midwater	*Melanostigma pammelas*		x	x
Oarfish, Crested	*Lophotus lacepede*	x		

Common Name	**Scientific Name**	**Epi-pelagic** (<200 m)	**Mesopelagic** (200-1000 m)	**Bathy-pelagic** (>1000 m)
Oarfish	*Regalecus glesne*	x	x	
King-of-the-salmon	*Trachipterus altivelis*	x	x	
Snailfish, Tadpole	*Nectoliparis pelagicus*		x	x
Snailfish, Pygmy	*Lipariscus nanus*		x	
Remora	*Remora remora*	x		
Yellowtail	*Seriola lalandi*	x		
Mackerel, Jack	*Trachurus summetricus*	x		
Pomfret, Sickle	*Taractichthys steindachneri*	x		
Pomfret, Pacific	*Brama japonica*	x		
Dolphinfish	*Coryphaena hippurus*	x		
Seabass, White	*Atractoscion nobilis*	x		
Barracuda, California	*Sphyraena argentea*	x		
Prowfish (juveniles)	*Zaprora silenus*	x		
Ragfish (juveniles)	*Icosteus aenigmaticus*	x		
Frostfish, North Pacific	*Benthodesmus pacificus*	x	x	
Oilfish	*Ruvettus pretiosus*	x	x	
Escolar	*Lepidocybium flavobrunneum*	x	x	
Mackerel, Pacific (Chub)	*Scomber japonicus*	x		
Mackerel, Bullet	*Auxis rochei*	x		
Tuna, Skipjack	*Katsuwonus pelamis*	x		
Bonito, Pacific	*Sarda chiliensis*	x		
Tuna, Albacore	*Thunnus alalunga*	x		
Tuna, Bigeye	*Thunnus obesus*	x		
Tuna, Bluefin	*Thunnus thynnus*	x		
Tuna, Yellowfin	*Thunnus albacares*	x		
Swordfish	*Xiphias gladius*	x		
Marlin, Striped	*Tetrapturus audax*	x		
Louvar	*Luvarus imperialis*	x		
Medusafish	*Icichthys lockingtoni*	x		
Driftfish, Bluefin	*Psenes pellucidus*	x	x	
Squaretail, Smalleye	*Tetragonurus cuvieri*	x		
Butterfish, Pacific	*Peprilus simillimus*	x		
Sunfish, Ocean	*Mola mola*	x		

Table 17. Taxa observed at Davidson Seamount and their listing categories.
Biological observations are from 17 ROV *Tiburon* dives (~140 hours of video and sample collections) completed during 2002 and 2006; primarily on the seafloor, with opportunistic dives in the water column above the seamount (Burton and Lundsten 2008). Taxa are listed in phylogenetic order. Listing categories for species of special interest are defined in Table 1.

Phylum	Taxa	Common Name	Listing Category		
			Landed	E/T	At-Risk
Foraminifera	XENOPHYOPHOREA sp. 1	xenophyophore, unidentified			
	XENOPHYOPHOREA sp. 2	xenophyophore, unidentified			
Radiozoa	RADIOLARIA spp.	radiolarian, unidentified			
Phaeophyta	*Alaria marginata*	kelp, ribbon (drift)			
	Alaria sp.	kelp, ribbon (drift)			
	Macrocystis sp.	kelp, giant (drift)			
	Nereocystis luetkeana	kelp, bull (drift)			
Anthophyta	*Phyllospadix* sp.	surfgrass (drift)			
Porifera	PORIFERA sp. 1	sponge			
	PORIFERA sp. 2	sponge			
	PORIFERA sp. 3	sponge			
	PORIFERA sp. 4	sponge, striated			
	PORIFERA sp. 5	sponge, stalked (white)			
	PORIFERA sp. 6	sponge			
	PORIFERA sp. 7	sponge, stalked ruffled (white)			
	PORIFERA sp. 8	sponge, ruffled (yellow)			
	PORIFERA sp. 9	sponge, encrusting gray			
	Thenea muricata	sponge			
	POECILOSCLERIDA sp.	sponge, stalked flute			
	Asbestopluma sp. nov.	sponge, branched (white)			
	Asbestopluma sp. 1	sponge, single (white)			
	Heterochone calyx	sponge, goiter (yellow/orange)			
	Chonelasma sp. nov.	sponge, trumpet (white)			
	Farrea occa	sponge, ruffle (white)			
	Sclerothamnopsis compressa	sponge			
	Saccocalyx pedunculata	sponge, stalked goiter (white)			
	Atlantisella sp. nov.	sponge, creeping (white)			
	Regadrella sp. nov.	sponge, vase (white)			
	Caulophacus sp. nov.	sponge, mushroom (white)			
	Crateromorpha sp. nov.	sponge			
	Hyalascus sp. nov.	sponge			
	Staurocalyptus sp. nov.	sponge, yellow			
Cnidaria	*Atolla* sp.	jelly, crown			
	Periphylla periphylla	jelly, crown			
	Poralia rufescens	jelly			

Phylum	Taxa	Common Name	Listing Category		
			Landed	E/T	At-Risk
	Tiburonia granrojo	jelly, big red			
	HYDROZOA sp. 1	hydroid			
	HYDROZOA sp. 2	hydroid			
	HYDROZOA sp. 3	hydroid			
	HYDRACTINIIDAE sp. nov.	hydroid			
	Chiarella sp.	hydroid			
	MYRIOTHELIDAE sp.	hydroid			
	Aegina citrea	narcomedusa, golf tee			
	Aegina sp.	narcomedusa			
	Aeginura sp.	narcomedusa			
	Cunina sp.	narcomedusa, mesopelagic			
	Solmissus sp.	narcomedusa			
	Halicreas minimum	jelly			
	Benthocodon sp.	jelly			
	Colobonema sericeum	medusa, silky			
	Crossota millsae	jelly			
	Nanomia bijuga	siphonophore			
	Stephanomia amphytridis	siphonophore			
	Apolemia sp.	siphonophore			
	Physophora hydrostatica	siphonophore			
	Stephalia dilata	siphonophore, benthic			
	Thermopalia taraxaca	siphonophore			
	Gymnopraia lapislazula	siphonophore			
	Trissopathes pseudotristicha	black coral			
	Trissopathes sp. (cf. *T. tetracrada*)	black coral			
	Bathypathes sp.	black coral			
	Lillipathes sp.	black coral			
	Umbellapathes sp.	black coral			
	CERIANTHIDAE sp. 1	tube-dwelling anemone			
	CERIANTHIDAE sp. 2	tube-dwelling anemone			
	CERIANTHIDAE sp. 3	tube-dwelling anemone			
	ACTINIARIA sp. 1 (poss. *Bathyphellia* sp.)	anemone			
	ACTINIARIA sp. 2	anemone			
	ACTINIARIA sp. 3	anemone			
	ACTINOSTOLIDAE spp.	anemone			
	Stomphia sp. (prob. *S. didemon)*	anemone			
	HORMATHIIDAE sp.	anemone			
	Liponema brevicornis	anemone, pom-pom			

Phylum	Taxa	Common Name	Listing Category		
			Landed	E/T	At-Risk
	ZOANTHIDEA sp. 1	zoanthid			
	ZOANTHIDEA sp. 2	zoanthid			
	CORALLIMORPHARIA spp.	anemone			
	Corallimorphus sp.	anemone			
	CARYOPHYLLIINA sp.	coral, stony			
	Javania cailleti	coral, stony			
	Anthomastus ritteri	coral, mushroom soft			
	Anthomastus robustus	coral, soft			
	Anthomastus sp. 1	coral, soft			
	Paragorgia arborea	coral, bubble gum			
	Paragorgia sp. 1	coral, bubble gum			
	Sibogagorgia cauliflora	coral, bubble gum (white morph)			
	Corallium sp.	coral, precious			
	Acanthogorgia sp.	coral			
	Swiftia kofoidi	coral, red sea fan			
	Chrysogorgia monticola	coral, golden gorgonian			
	Chrysogorgia pinnata	coral, golden gorgonian			
	Calyptrophora bayeri	coral			
	Calyptrophora sp. (cf. *C. antilla*)	coral			
	Calyptrophora sp.	coral			
	Narella sp.	coral			
	Parastenella ramosa	coral			
	Parastenella sp.	coral			
	Acanella sp.	coral, bamboo			
	Keratoisis sp.	coral, bamboo			
	Lepidisis sp.	coral, bamboo			
Ctenophora	*Aulacoctena* sp.	ctenophore			
	Hormiphora sp.	ctenophore			
	Tjalfiella tristoma	ctenophore			
	LOBATA sp. nov.	ctenophore, lobate			
	Bathocyroe spp.	ctenophore, lobate			
	Lampocteis cruentiventer	ctenophore, lobate			
	Lampocteis sp.	ctenophore, lobate			
Mollusca	PATELLOIDEA sp.	limpet			
	TURRIDAE sp.	turrid			
	NUDIBRANCHIA sp. nov.	nudibranch, mystery mollusk			
	Tritonia sp. (cf. *T. diomedea* or sp. nov.)	nudibranch			
	BATHYDORIDIDAE sp.	nudibranch			

Phylum	Taxa	Common Name	Listing Category		
			Landed	E/T	At-Risk
	NEOLORICATA sp.	chiton			
	Acesta mori	clam			
	?PECTINIDAE sp.	scallop			
	Doryteuthis (=Loligo) opalescens	squid, California market	X		
	Galiteuthis sp.	squid, glass			
	Gonatus onyx	squid, clawed armhook			
	Dosidicus gigas	squid, Humboldt	X		
	Opisthoteuthis sp.	devilfish, flapjack			
	Japetella sp.	octopus, pelagic			
	Benthoctopus sp.	octopus, benthic			
	Graneledone boreopacifica (pacifica)	octopus			
Annelida	*Tomopteris* sp.	polychaete, tomopterid			
	Laetmonice sp.	polychaete, sea mouse			
	POLYNOIDAE sp.	scale worm, blue			
	Euchone sp. nov.	polychaete, sabellid			
	SERPULIDAE spp.	polychaete, serpulid			
	Poeobius meseres	polychaete, holopelagic			
	Flota sp.	polychaete			
Arthropoda	PYCNOGONIDA sp.	sea spider			
	SCALPELLOMORPHA sp.	barnacle, stalked			
	VERRUCOMORPHA sp.	barnacle			
	Sergestes similis	shrimp, midwater			
	CARIDEA spp.	shrimp			
	Pandalopsis ampla	shrimp, deepwater bigeye			
	LITHODIDAE sp. (probably juvenile)	crab, (probably juvenile)			
	Neolithodes diomedeae	crab			
	Neolithodes sp.	crab, spiny			
	Paralomis multispina	crab			
	Paralomis verrilli	crab, vermillion			
	Munida sp.	lobster, squat			
	Munidopsis spp.	lobster, squat			
	BRACHYURA sp.	crab			
	Chorilia longipes	crab, longhorn decorator			
	MYSIDA spp.	shrimp, opossum			
	AMPHIPODA spp.	amphipod			
	CAPRELLIDAE spp.	caprellid			
	ISOPODA spp.	isopod			
	MUNNOPSIDAE spp.	isopod			

Phylum	Taxa	Common Name	Listing Category		
			Landed	E/T	At-Risk
Ectoprocta	ECTOPROCTA sp. 1	bryozoan			
	ECTOPROCTA sp. 2	bryozoan			
Echinodermata	*Hyocrinus* sp.	crinoid, 5-arm			
	BATHYCRINIDAE sp.	crinoid, 10-arm			
	Florometra serratissima	crinoid, (feather star)			
	Benthopecten sp. (possibly *B. claviger)*	sea star, prickly			
	Ceramaster patagonicus	sea star			
	Ceramaster sp.	sea star			
	Evoplosoma voratus	sea star			
	Hippasteria californica	sea star			
	Hippasteria spinosa	sea star			
	Mediaster spp.	sea star			
	Hymenaster koehleri	sea star			
	?Pteraster sp. 1	sea star			
	Pteraster sp. 2 (possibly *Hymenaster* sp.)	sea star			
	Pteraster sp. 3 (possibly *Hymenaster* sp.)	sea star			
	Pteraster sp. 4	sea star			
	Pteraster sp. 5	sea star			
	Lophaster furcilliger	sea star			
	Solaster spp.	sun star			
	Henricia sp.	sea star			
	?Anteliaster sp.	sea star			
	Myxoderma sacculatum	sea star			
	ZOROASTERIDAE sp.	sea star, pink			
	BRISINGIDA spp.	sea star, brisingid			
	OPHIUROIDEA spp.	brittle star			
	Gorgonocephalus sp.	basket star			
	OPHIACANTHIDAE sp.	brittle star			
	ECHINOIDEA sp.	urchin			
	Aporocidaris milleri	urchin, pencil			
	Tromikosoma panamense	urchin			
	Tromikosoma sp.	urchin			
	Cystocrepis setigera	urchin			
	HOLOTHUROIDEA sp. 1	sea cucumber			
	HOLOTHUROIDEA sp. 2	sea cucumber			
	Abyssocucumis abyssorum	sea cucumber			
	Psolus squamatus	sea cucumber			
	Paelopatides confundus	sea cucumber			

Phylum	Taxa	Common Name	Listing Category		
			Landed	E/T	At-Risk
	SYNALLACTIDAE sp.	sea cucumber			
	Oneirophanta mutabilis	sea cucumber			
	Peniagone sp.	sea cucumber			
	Scotoplanes globosa	sea cucumber			
	Pannychia moseleyi	sea cucumber			
	Benthodytes sp. 1	sea cucumber			
	Benthodytes sp. 2	sea cucumber			
Chaetognatha	CHAETOGNATHA spp.	chaetognath			
Hemichordata	ENTEROPNEUSTA sp.	acorn worm			
Chordata	*Culeolus* sp.	tunicate, stalked			
	SALPIDA spp.	salp			
	Doliolenetta sp. nov.	salp			
	DOLIOLIDA spp.	salp			
	Bathochordaeus sp.	larvacean, Giant			
	APPENDICULARIA spp.	larvacean			
	RAJOIDEI spp.	skate, egg cases, unidentified			
	Bathyraja abyssicola	skate, deepsea			
	Amblyraja badia	skate, broad			
	Aldrovandia sp.	lizardfish, salty (or halosaur)			
	SYNAPHOBRANCHIDAE sp.	eel, cutthroat			
	Venefica tentaculata	eel, witch			
	Serrivomer sp. (possibly *S. sector)*	eel, sawtooth			
	Cyema atrum	eel, bobtail			
	BATHYLAGIDAE spp.	smelt, deep-sea			
	ALEPOCEPHALIDAE sp. (poss. *Conocara salmoneum*)	slickhead			
	Cyclothone sp.	bristlemouth			
	Bathysaurus mollis	lizardfish, highfin			
	MYCTOPHIDAE spp.	lanternfish			
	Luciobrotula sp.	brotulid			
	Spectrunculus grandis	cusk-eel, giant			
	Albatrossia pectoralis	grenadier, giant			
	Coryphaenoides acrolepis	grenadier, Pacific	X		
	Coryphaenoides armatus/yaquinae	grenadier, abyssal/rough abyssal			
	Coryphaenoides filifer	grenadier, filamented			
	Coryphaenoides leptolepis	grenadier, ghostly			
	Antimora microlepis	codling, finescale (or Pacific flatnose)			
	MORIDAE sp. *(Lepidion* sp.	codling			

Phylum	Taxa	Common Name	Listing Category		
			Landed	E/T	At-Risk
	or possibly *Laemonema* sp.*)*				
	Chaunocops coloratus	sea toad, deep			
	Sebastolobus alascanus	thornyhead, shortspine	X		EN
	Psychrolutes phrictus	sculpin, blob (or no-name)			
	Careproctus ovigerus (juvenile)	snailfish, abyssal (juvenile)			
	LIPARIDAE sp.	snailfish, unidentified (blackhead)			
	Bothrocara brunneum	eelpout, twoline			
	Lycenchelys spp.	eelpout			
	Lycodapus fierasfer	eelpout, blackmouth			
	Lycodapus mandibularis	eelpout, pallid			
	Pachycara bulbiceps	eelpout, snubnose			
	ZOARCIDAE spp.	eelpout			

Table 18. Dominant invertebrate phyla observed at Davidson and Pioneer Seamounts.
Percent observation of three dominant invertebrate phyla, and for taxa within each of the three dominant phyla, are listed (from Lundsten et al. 2009a). Mean organism density (all taxa observed within transects) was calculated from quantitative video transects at Davidson (n=33; between 1298 and 3276 m depth) and Pioneer (n=7; between 844 and 1240 m depth), and was significantly different between the two seamounts (2-tailed *t*-test, $t(38)=-5.13$, $p<0.001$).

Phylum	Taxa	Common Name	% Observation	
			Davidson Seamount	Pioneer Seamount
Porifera			29.5	20.2
	Chonelasma sp.	sponge, trumpet	6.4	9.7
	Farrea sp.	sponge, ruffle	22.5	11.4
	Heterochone sp.	sponge, goiter	5.9	17.7
	Schlerothamnopsis sp.	sponge	14.8	1.7
	Staurocalyptus sp.	sponge	13.2	13.1
	Thena muricata	sponge	rare	16.1
	unidentified	sponge, unidentified	31.9	25.4
Cnidaria			34.2	39.8
	Alcyonacea	coral, soft	4.7	38.6
	Anthipatharia	coral, black	21.8	0.2
	Gorgonians	sea fan/sea whip	73.0	61.0
	Pennatulacea	sea pens	rare	rare
	Scleractinia	coral, stony	0.4	0.15
	Zoanthidea	anemone, zoanthid	0.09	0.0
Echinodermata			32.4	34.4
	Asteroidea	sea stars	10.3	9.0
	Crinoidea	feather stars	44.6	61.7
	Echinoidea	urchins	0.4	0.02
	Holothuroidea	sea cucumbers	16.1	23.4
	Ophiuroidea	brittle stars	28.7	5.9
Mean organism density			*0.87 ± 0.10 ind./m²*	*2.19 ± 0.27 ind./m²*

Table 19. Dominant fish families observed at Davidson and Pioneer Seamounts.
Percent observation of eight dominant fish families at Davidson and Pioneer Seamounts (from Lundsten et al. 2009b). Mean fish density (all taxa observed within transects) was calculated from quantitative video transects at Davidson (n=33; between 1298 and 3276 m depth) and Pioneer (n=7; between 844 and 1240 m depth), and differed between the two seamounts.

Family	**Common Name**	**% Observation**	
		Davidson Seamount	**Pioneer Seamount**
Bythitidae	brotulas	3.8	1.3
Liparidae	snailfishes	11.5	4.6
Macrouridae	grenadiers	53.1	37.8
Moridae	codlings	10.2	8.8
Ophidiidae	cusk-eels	14.7	0.3
Pleuronectidae	righteye flounders	0.3	1.6
Scorpaenidae	scorpionfishes	0.3	42.1
Zoarcidae	eelpouts	5.2	3.0
Mean fish density		*0.0028±0.0006 ind/m²* *(n = 22 taxa)*	*0.025 ± 0.0024 ind/m²* *(n = 18 taxa)*

Table 20. Sea-surface species observed within Davidson Seamount Management Zone.
Sea-surface species were recorded during four aerial surveys and two ship-based surveys within the Davidson Seamount Management Zone (DSMZ). Species are listed in phylogenetic order. Listing categories for species of special interest are defined in Table 1. E/T = Endangered/Threatened; SSC = Species of Concern; VU = Vulnerable; EN = Endangered

Common Name	Scientific Name	Survey						Listing Category		
		Aerial				Shipboard				
		2000 Jul [1]	2009 Apr [2]	2010 Jan [3]	2010 Apr [3]	2002 May [4]	2010 Jul [5]	Landed	E/T	At-Risk
Fishes										
shark, unidentified	shark, unidentified				X	X				
sunfish, ocean	*Mola mola*	X		X	X	X		X		
Seabirds and Shorebirds										
Albatross, Laysan	*Phoebastria immutabilis*			X		X				VU
Albatross, Black-footed	*Phoebastria nigripes*	X				X				EN
Fulmar, Northern	*Fulmarus glacialis*			X		X				
Petrel, Stejneger's	*Pterodroma longirostris*					X				VU
Petrel, Cook's	*Pterodroma cookii*						X			VU
Shearwater, Pink-footed	*Puffinus creatopus*					X	X			VU
Shearwater, Sooty	*Puffinus griseus*					X				
Shearwater, unidentified	*Puffinus* sp.					X				
Storm-petrel, Leach's	*Oceanodroma leucorhoa*					X	X			
Storm-petrel, unidentified	*Oceanodroma* sp.			X		X				
Plover, Black-bellied	*Pluvialis squatarola*						X			
Sandpiper, Least	*Calidris fuscicollis*						X			
Phalarope, Red	*Phalaropus fulicaria*						X			
Phalarope, Red-necked	*Phalaropus lobatus*						X			
Jaeger, Parasitic	*Stercorarius parasiticus*					X				
Jaeger, Pomarine	*Stercorarius pomarinus*					X				
Jaeger, unidentified	*Stercorarius* sp.					X				
Gull, Western	*Larus occidentalis*					X				
gull, unidentified	gull, unidentified					X				

Common Name	Scientific Name	Survey						Listing Category		
		Aerial				Shipboard				
		2000 Jul [1]	2009 Apr [2]	2010 Jan [3]	2010 Apr [3]	2002 May [4]	2010 Jul [5]	Landed	E/T	At-Risk
Tern, Arctic	*Sterna paradisaea*						X			
Murrelet, Xantus's	*Synthliboramphus hypoleucus*						X		T	VU
alcid, unidentified	alcid, unidentified			X						
Marine Mammals										
fur seal, Northern	*Callorhinus ursinus*						X			VU
fur seal, unidentified	fur seal, unidentified					X	X			
sea lion, California	*Zalophus californianus*			X	X	X	X			
otariid, unidentified	otariid, unidentified					X				
elephant seal, Northern	*Mirounga angustirostris*						X			
pinniped, unidentified	pinniped, unidentified		X							
whale, gray	*Eschrichtius robustus*			X						
whale, humpback	*Megaptera novaeangliae*				X	X			E	
whale, fin	*Balaenoptera physalus*						X		E	EN
rorqual, unidentified	rorqual, unidentified						X			
whale, sperm	*Physeter macrocephalus*		X	X	X	X			E	VU
beaked whale, Cuvier's	*Ziphius cavirostris*			X						
whale, unidentified	whale, unidentified			X	X					
dolphin, Pacific white-sided	*Lagenorhynchus obliquidens*					X	X			
dolphin, Northern right whale	*Lissodelphis borealis*					X	X			
dolphin, Risso's	*Grampus griseus*	X								
whale, killer	*Orcinus orca*			X		X			*	
porpoise, Dall's	*Phocoenoides dalli*					X	X			
dolphin, unidentified	dolphin, unidentified			X	X					

[1] Forney 2002; [2] CINMS, unpublished data; [3] King and DeVogelaere, MBNMS, unpublished data; [4] Benson 2002, [5] Newton et al. 2011
* It could not be determined if the individuals sighted were members of the "Endangered" southern resident killer whale population or other non-listed populations of killer whales.

Table 21. Species observed at four CBCs in Monterey Bay.
Organisms are listed by scientific name and the higher taxonomic groups to which the organisms belong are provided (from Barry et al. 1996). Obligate species are species that are only found at CBCs or other areas where chemosynthesis is possible (e.g. whale falls, hydrothermal vents). Y = yes, N = no, U = unknown, ? = information is uncertain.

Taxonomic Group	Scientific Name	Obligate Species?
Bacteria	*Beggiatoa* sp.	Y
Cnidaria		
Anthozoa	*Anthomastus ritteri*	N
	Umbellula lindahli	N
	Stomphia sp.	N
	Paractinostola sp.	N
	Unknown sp.	N
Mollusca		
Polyplacophora	*Leptochiton* sp.	U
Gastropoda	Unknown sp.	U
	Pyropelta sp.	U
	Neptunea amianta	N
	Amphissa bicolor	N
	Mitrella permodesta	Y
Bivalvia	*Solemya* sp.	Y
	Nuculana sp.	N
	Yoldia sp.	N
Vesicomyidae	*Phreagena kilmeri*	Y
	Calyptogena pacifica	Y
	Calyptogena packardana sp. nov.	Y
	Calyptogena c.f. phaseoliformis	Y
	Vesicomya gigas	Y
	Vesicomya stearnsii	Y
	Unknown sp.	Y
Annelida		
Polychaeta	*Eclysippe* sp.	N
	Ampharetidae genus 1	N
	Chloeia sp.	N
	Capitella capitata	N
	Brada sp.	N
	Pherusa sp.	N
	Nereis sp. 1	N
	Nereis sp. 2	N
	Lepidonotus sp.	N
	Amphitritnae sp.	N
	Terebellides sp.	N
Pogonophora	*Polybrachia* sp.	Y
Vestimentifera	*Lamellibrachia barhami*?	Y
Arthropoda		
Decapoda	Paguridae-unknown sp.	N
	Lithodes aequispina?	N
	Lithodes couesi?	N
	Chorilia longipes	N
	Chionoecetes tanneri	N
	Munidopsis sp.	Y?
	Munida quadrispina	N

Taxonomic Group	**Scientific Name**	**Obligate Species?**
Brachiopoda	*Terebratulina* sp.	N
	Laqueus californianus californica	N
	L.c. vancouveriensis	N
	Glottidia albida?	N
Echinodermata		
Crinoidea	*Florometra serratissima*.	N
Asteroidea	*Thrissacanthias penicillatus*	N
	Hippasteria californica	N
	Solaster borealis	N
	Pteraster jordani?	N
	Zoraster sp.	N
	Rathbunaster californicus	N
	Brisingella? sp.	N
	Unknown sp.	N
Ophiuroidea	Unknown sp.	N
	Asteronyx loveni	N
Echinoidea	*Strongylocentrotus fragilus*	N
	Brisaster latifrons	N
Holothuroidea	*Psolus* sp.	N
	Pannychia moseleyi	N
Chordata		
Agnatha	*Eptatretus* sp.	N
Chondrichthyes	*Apristurus brunneus*	N
Osteichthyes	*Coryphaenoides acrolepis*	N
	Nezumia stegidolepis?	N
	Aprodon cortezianus	N
	Sebastolobus alascanus	N
	Sebastolobus altivelis	N
	Embassichthys bathybius	N
	Microstomus pacificus	N

Appendix I. Catalogue of Research Studies

Listed alphabetically by author.

Study	Timing of Study	Location of Study	Habitat (depth; substrate)	Sampling Method
Anderson and Yoklavich 2007	October 1993	Pt. Pinos, Monterey Bay, California	60-260 m, hard and soft bottom	Manned submersible, video
Anderson et al. 2009	September 2002	Cordell Bank, central California	Shelf, slope; hard and soft bottom	Manned submersible, video
Barry et al. 1996, 1997	1992-1994	Monterey Bay, California	600-1000 m; soft bottom	ROV, sediment cores
Barry et al. 2004	June-July 2001	85 nm west of Moss Landing, California	3600 m	ROV, PVC corrals
Becker and Beissinger 2006	1895-1911, 1998-2002	Central California	Open water	Stable isotope chemistry
Benson 2002	May 2002	Davidson Seamount	Open water	Shipboard surveys
Benson et al. 2002	Summer 1996-1999	Monterey Bay, California	Open water	Line-transect shipboard surveys
Benson et al. 2007	Late summer & fall, 1990-2003	Oregon-California border to Pt. Conception, California	Coast to 92 m isobath; open water	Aerial line-transect surveys
Benson et al. 2011	2000-2007	Pacific Ocean	Open water	Satellite telemetry
Bianchi 2011	September 1994	Ascension and Carmel Canyons, California	90-319 m, canyon; soft and hard bottom	Manned submersible
Bizzarro et al. 2003	October 2001	Ascension and Año Nuevo Canyons, California	200-350 m, canyon; soft and hard bottom	Manned submersible
Bjorkstedt et al. 1997, 2002	Upwelling seasons, 1993 & 1994	Central California	Open water	Tucker trawl with 200 µm mesh
Brown 2006	1998-2000	Monterey Bay, California	0-200 m; soft bottom	Otter trawl
Burton and Lundsten 2006	September 2006	Pt. Sur, central California	430 m; soft bottom	ROV, video
Burton and Lundsten 2008	May 2002, Jan/Feb 2006	Davidson Seamount	1246-3289 m; soft and hard bottom; seamounts	ROV video and collection
Butler et al. 1989 (and Wakefield unpubl. data)	Jan/Feb 1987, Mar/Apr 1988	Half Moon Bay to Purisima Pt., central California	100-1500 m; soft bottom	Bottom trawls
Cailliet et al. 1992, 1999	1988, 1991, 1992	West of Farallon Islands, near Pioneer Canyon, near Monterey Canyon	2300-3300 m; soft bottom	Otter trawl, beam trawl, traps, camera sled, submersible
Carr et al. 2008	N/A	Monterey Bay, California	Open water	ROMS model

Study	Timing of Study	Location of Study	Habitat (depth; substrate)	Sampling Method
Carretta et al. 2009	2002-2007	OR/CA border to Pt. Conception, California	Open water	Aerial surveys
Chavez 1996	1992	Monterey Bay, California	Open water	Temperature, salinity, wind, nutrients, chlorophyll, phytoplankton
Chavez et al. 2002	1989-1999	Central California	Open water	CTD casts, bottle samples, moorings, SeaWiFS satellite
Chavez et al. 2003	1910-2000	Eastern North Pacific	Open water	CO_2, air and sea surface temperature; seabird, anchovy, sardine abundance
Croll et al. 2005	1992-1996	Monterey Bay, California	Open water, canyon	Shipboard surveys
CSLC & MBNMS 2005	Aug – Oct 2003	Monterey Bay, California	25-885 m; mostly soft bottom	ROV, video, Smith-McIntyre grabs, push cores
Davis et al. 2002	1978, 1979, 1998, 2000	Davidson, Guide, Pioneer, Gumdrop, Rodriquez Seamounts	1119-2860 m; hard bottom; seamounts	Multibeam and side-scan mapping; dredge and ROV rock collection
Davis et al. 2007	1976, 1978, 1979, 2000, 2002	Pioneer and Davidson Seamounts	1000-3500 m; hard bottom, seamounts	Dredge and ROV collections
de Marignac and Burton 2003	September 2003	Cambria, central California	275 m; soft bottom	Manned submersible, video
deMarignac et al. 2009	June 2006	CBNMS and GFNMS	113-152 m; soft bottom	ROV surveys, sediment grab samples
Doyle et al. 2002	1980-1994 (seven cruises in spring)	Washington to California	Open water	Ichthyoplankton tows
Drazen et al. 2001	1997-1998	US/Canada border to Pt. Conception, California	188-1260 m; substrate not specified	Bottom trawl and tube traps
Drazen et al. 2003	Summer, 2000-2002	Gorda Escarpment, northern California	1300-3000 m; soft and hard bottom	ROV video
Ebert and Davis 2007	May 2002, January 2006	Davidson Seamount	1310-1319 m; hard bottom; seamounts	ROV collection
Engel and Kvitek 1998	1994-1996	Pt. Lobos to Pt. Sur, central California	180 m; soft bottom	Photos, videos, bottom grab samples, bottom trawling
Firme et al. 2003	Summer 1999	Pt. Arena to Pt. Conception, California	Open water (over shelf and slope)	Surface water sampling
Foote et al. 2006	May 2003, May 2004	Southern Monterey Bay, California	25-40 m; soft bottom	Video camera, ROV, sidescan sonar

Study	Timing of Study	Location of Study	Habitat (depth; substrate)	Sampling Method
Forney et al. 2001	1990-1998	Monterey Bay, California	Open water	Bycatch observations, fishing effort, beach deposition rates
Forney 2002	July 2000	Davidson Seamount and MBNMS	Open water	Aerial line-transect surveys
Forney et al. 2012	1986-2006	California Current Ecosystem	Open water	Shipboard surveys, oceanographic data (various sources)
Forsythe et al. 2004	Spring & fall 2000, summer 2001	Southern Monterey Bay, California	20-60 m; soft bottom	ROV, video
Glover and Smith 2003	1989-1996; literature review	Station M (west of Pt. Sal, California)	4100 m; soft bottom	N/A
Goffredi et al. 2003	1991-2001	Eastern Pacific Ocean, including Monterey Bay, California	650-2200 m; chemosynthesis-based communities	Manned submersible, ROV
Gofffredi et al. 2004	February-October 2002	Monterey Canyon, California	2891 m; soft bottom	ROV, photos, sediment cores
Graham 1994; Graham and Largier 1997	1988-1993	Monterey Bay area, California	Open water	Salinity, temperature, nutrients, currents, productivity
Graham et al. 2010	March-November 2003-2007	Bodega Bay to Monterey Bay, California	Open water	Tucker trawl, midwater trawl, ecosounders
Graiff 2008	1993, 1994, 1997, 1998	Portuguese Ledge, Pt. Sur, Big Creek, central California	19-252 m; hard and soft bottom	Manned submersible, video
Greene et al. 2002	May-June 1998	Central California	30-3700 m; hard and soft bottom	Multibeam sonar
Harrold et al. 1998	1989-1991	Pt. Joe and Carmel Canyon, central California	Shelf/slope: 87-357 m, canyon: 153-454 m; soft bottom	ROV surveys
Hixon and Tissot 2007	September 1990	Coquille Bank, Oregon	183-361 m; soft bottom	Visual surveys from manned submersible
Hunter et al. 1990	1985-1988	Half Moon Bay to Pt. Conception, California	69-1394 m; soft bottom	Bottom trawls, Nansen bottles
Hutchins et al. 1998	June 1996, June 1997	Mendocino and Big Sur coasts, California	Open water, over shelf	Surface water sampling
Hyland 1991	1986-1989	Purisima Pt. to Pt. San Luis, Santa Maria Basin, California	90-565 m; soft bottom	Box cores, near-bottom hydrocasts
IfAME and MBNMS 2011	2007-2010	Pt. Ano Nuevo to Pt. Piedras Blancas, California	50-400 m; hard and soft bottom, canyon	ROV, towed camera sled, video transects
Jacobson and Vetter 1996	March-April 1988	Pt. Sur to Pt. Conception, central California, and	200-1400 m; primarily soft bottom	Bottom trawls

Study	Timing of Study	Location of Study	Habitat (depth; substrate)	Sampling Method
		Oregon		
Jacobson et al. 2001a	1988-1997	Washington to Lopez Pt., central California	183-1280 m; primarily soft bottom	Commercial bottom trawl surveys
Johnson et al. 2001	March 1995 – February 1996	Monterey Bay, California	40-100 m; primarily soft bottom	Otter trawl
Jorgensen et al. 2009	2000-2008	Eastern North Pacific	Open water; over nearshore and shelf	Satellite PAT tags
Keiper et al. 2005	1986-1994 and 1997-1999	Bodega Bay to Cypress Pt., California	Open water, coast to 250 km offshore	Ship transects
Kelly and Klimley 2003	October 2000 – February 2001	Pt. Reyes Headlands, California	Open water; over nearshore and shelf	Shipboard observations
Klimley et al. 2001	October 1997	Año Nuevo Island, California	Open water; over nearshore and shelf	Tracking with ultrasonic tags
Kogan et al. 2006	October 2002, February and July 2003	Pillar Pt. to Pioneer Seamount, California	14-2000 m; primarily soft bottom	Side-scan sonar, ROV, video, sediment cores
Kuhnz et al. 2011	November 2007-April 2008; January-April 2010	Northern Monterey Bay to Smooth Ridge	19-1007 m; primarily soft bottom	ROV video, sediment cores
Laidig et al. 2009	August-September 2004	Davenport, California	65-110 m; primarily hard bottom	Manned submersible, video
Larson et al. 1994	April & May/June, 1987 & 1988	Pt. Reyes to Monterey, California	Open water	Midwater trawls
Lea et al. 1999	July 1978-December 1985	Monterey Bay to Morro Bay, central California	10-110 m; primarily hard bottom	Hook-and-line, spearfishing
Lenarz et al. 1991	mid-May- June & late March - mid-April, 1983 -1990	Pt. Reyes to Monterey, California	Open water	Modified Cobb midwater trawl
Levin et al. 2006	June-August 1980-2001	U.S. west coast (WA, OR CA)	55-366 m; soft bottom	Fishery-independent bottom trawls
Little 2003	January 1998-December 2001	Monterey Bay, California	Open water	CTD, temperature array, ACDP, fluorometer, net tows
Lundsten 2007	2006, 2007	Davidson, Pioneer and Rodriguez Seamounts	619-3289 m; soft and hard bottom; seamounts	ROV video
Lundsten et al. 2009a	2006, 2007	Davidson, Pioneer and Rodriguez Seamounts	619-3289 m; soft and hard bottom; seamounts	ROV video
Lundsten et al. 2009b	2006, 2007	Davidson, Pioneer and Rodriguez Seamounts	619-3289 m; soft and hard bottom;	ROV video

Study	Timing of Study	Location of Study	Habitat (depth; substrate)	Sampling Method
			seamounts	
Lundsten et al. 2010	2002-2009	Monterey Canyon	382-2893 m; soft bottom; canyon	ROV video
Marinovic et al. 2002	May to November in 1997–1999	Monterey Bay, California	Open water	CTD casts, hydro-acoustic zooplankton sampling, Bongo nets
MBARI 2009a	1998	Davidson, Pioneer, Guide, Gumdrop Seamounts	800-4000 m; hard and soft bottom; seamounts	Multibeam mapping
McClain et al. 2009	2000, 2002, 2006, 2007	Davidson Seamount	1246-3656 m; soft and hard bottom; seamounts	ROV video and collection
McClain et al. 2010	2006	Davidson Seamount	1246-3656 m; soft and hard bottom; seamounts	ROV video and collection
Mullins et al. 1985	1981	Pt. Lobos to Pt. Sur, California	300-1400 m; soft bottom	Box cores, gravity cores, bottom photographs
Nelson et al. 2008	June 2003	West coast of Washington, Oregon and California	40-112 m; soft bottom	Sediment grabs
Newton et al. 2011	July 2010	Davidson Seamount	Open water	Seabird and marine mammal shipboard surveys
NMFS-NWFSC unpubli. data	1999-2006	MBNMS	200-1200 m	Bottom trawl
Novikov 1970	1962-1965	North Pacific (Bering Sea, Sea of Okhotsk, Aleutian Islands)	200-1200 m; soft-bottom	Bottom trawl
Nur et al. 2011	1997-2008	West coast of Washington, Oregon and California	Open water	Seabird shipboard surveys, oceanographic data (various sources)
Nybakken et al. 1998	1988, 1991, 1992	West of Farallon Islands, Pioneer Canyon, Monterey Canyon, California	1085-3300 m; soft bottom	Camera sled, beam trawl, otter trawl
Okey 2003	1988-1991	Monterey Canyon head, California	30-500 m; soft bottom	Experimental manipulation of macrophyte patches, ROV, sediment cores
Oliver and Slattery 1976	June 1971-April 1973	Monterey Canyon head, California	<30m; soft bottom	Sediment cores
Oliver et al. 2011	1999-2006	OR/CA border to Pt. Conception, California	30-2000 m, soft bottom	Sediment grabs
Paull et al. 2005a	1989-2002	Monterey Bay, California	Slope, canyon; soft and hard bottom	ROV, video database

Study	Timing of Study	Location of Study	Habitat (depth; substrate)	Sampling Method
Paull et al. 2005b	2000-2002	Monterey Bay, California	Canyon; soft bottom	ROV, video, sediment cores
Pearcy et al. 1977	1971-1975	Oregon	Shelf and slope; soft bottom	Bongo tows, midwater trawls, beam trawl
Pearcy et al. 1982	1963-1976	Oregon, Washington, central North Pacific	400-5180 m; soft bottom	Beam trawl, otter trawl
Pilskaln et al. 1996	August 1989 – December 1992	Station S1 and Station H3, Monterey Bay, California	Open water	Subsurface sediment traps (450 m at S1) and water samples (at H3)
Pirtle 2005	September 2002	Cordell Bank, California	55-250m; hard and soft bottom	ROV; 27 video transects
Pyle et al. 1996	1968-1992	South Farallon Islands, California	Open water; over nearshore and shelf	Shorebased observations
Rizk 2006	2000-2006	Davidson and San Juan Seamounts, California Current, California Undercurrent	Open water, seamounts	Analysis of oceanographic data from CalCOFI, SeaWiFS, MBARI AUV, National Data Buoy Center, MBARI M2 buoy
Robison et al. 2005	1994-2003	Axis of Monterey Canyon, California	Midwater abundance: 100-1000 m; seafloor sinkers: 200-2979 m; soft bottom	Quantitative video transects; ROV collections
Ruhl and Smith 2004	1989-2002	Station M (west of Pt. Sal, California)	4100 m; soft bottom	Photo line transects; otter trawl; sediment trap
Ryan et al. 2005	August 2000	Monterey Bay, California	Open water	AUV surveys, ADCP, SST remote sensing
SAIC and MLML 1992	September-October 1991	Gulf of the Farallones, Pioneer Canyon, west of Half Moon Bay, California	72-1800 m; soft bottom	Bottom trawls, ROV video and photo quadrats
Schlining and Spratt 2000	July 1996-June 1997	Carmel Canyon, California	200-400 m; primarily soft bottom	Commercial spot prawn traps
Scholin et al. 2000	May-June 1998	Central California	Open water	Remote sensing, phytoplankton samples, nutrients, histology, toxicology
Schroeder and Love 2002	1995-2000	Southern California Bight, California	100-300 m; primarily hard bottom	Manned submersible
Sekula-Wood et al. 2009	Nov 2004-June 2006, April 2006-Dec 2007	Southern California Bight, California	550-800m; soft bottom	Sediment traps
Silver et al. 1998	October 1989-January 1993	Monterey Bay, California	Open water	ROV, sediment traps

Study	Timing of Study	Location of Study	Habitat (depth; substrate)	Sampling Method
Sloan 1987	August 1986	Howe Sound, British Columbia, Canada	Shelf; soft bottom	Traps
Smith et al. 1989	November 1987, 1988	Santa Catalina Basin, California	1,240 m; soft bottom	ROV, sediment and bone samples
Smith et al. 2001	8 years	Station M (west of Pt. Sal, California)	Open water, 600 and 50 m above seafloor (4100 m)	Sediment traps
Spalding et al. 2003	1999-2000	Cypress Pt. to Pt. Sur, central California	30-77 m; hard bottom	SCUBA quadrats, ROV video transects
Starr et al. 1999	1999	Monterey Bay, California	5-375 m, canyon; primarily soft bottom	Acoustic tags, directional hydrophone, subsurface listening station
Starr et al. 2002b	1997-1998	Soquel Canyon, Monterey Bay, California	100-250 m (canyon flank); soft and hard bottom	Acoustic tags, longline gear, modified trolling gear
Starr et al. 2006	August 2004	Pt. Pinos and Pt. Sur, central California	70-130 m; hard bottom	Video strip transects from a manned submersible
Starr and Yoklavich 2008	2007	Soquel Canyon to Big Creek, central California	24-365 m; hard and soft bottom	Visual strip transects from a submersible, video
Sullivan 1995	May 1987-December 1992	Pescadero Pt. to Pt. Sur, central California	9-274 m; hard shelf (bottom habitat not assumed, not specified)	Hook and line fishing gear
Summers and Nybakken 2000	1990, 1991, 1992	West of Farallones, Pioneer Canyon, Monterey Canyon, California	550-3085 m; soft bottom	Box cores, bottom trawls
Tamburri et al. 2000	NA (≤1999)	Monterey Canyon, California	625 m	ROV, CO_2 release rig
Thistle et al. 2005	N/A	Monterey Bay, California	3,250 m; soft-bottom	ROV, CO_2 injection, sediment cores, pH
Thompson et al. 1985	1981	NW of Pt. Sur, central California	300-1400 m; soft bottom	Box cores, gravity cores, photo quadrats
Tissot et al. 2006	2002	Southern California	32-320 m; hard and soft bottom	Video transects from a submersible
Tolimieri 2007	1999-2002	Northern Washington to southern California (47°N to 33°N)	200-1200 m; soft bottom	Bottom trawls
Tolimieri and Levin 2006	1999-2002	Northern Washington to southern California (48°N to 32°N)	200-1200 m; soft bottom	Bottom trawls

Study	Timing of Study	Location of Study	Habitat (depth; substrate)	Sampling Method
Toole et al. 1997	1989-1994	Oregon	50-400 m; soft bottom	Commercial shrimp trawl
Vetter and Dayton 1998, 1999	July and August 1995	Scripps and La Jolla Canyon, southern California	100-900 m (shelf/slope, canyons); soft bottom	Sediment cores and ROV
Vetter et al. 1994	1991-1992	Smooth Ridge, Monterey Bay, California	100-1400 m; soft bottom	Bottom trawls, CTDs, Niskin bottles
Voight and Grehan 2000	Aug 1995, Oct 1997, July 1998	Cascadia Basin, Oregon	2600 m; hard bottom	Manned submersible, ROV, video
Wakefield 1990	May 1984-May 1985	Pt. Sur, California	200-1600 m; primarily soft bottom	Bottom trawl
Wakefield and Smith 1990	May 1984-May 1985	Monterey to Pt. Sur, central California	400-1600 m; primarily soft bottom	Bottom trawl
Watters et al. 2010	1993-94, 1997-98, 2007	Ascension Canyon to Big Creek Ecological Reserve, central California	20-365 m; primarily hard bottom	Delta submersible, video
Weng et al. 2007	1999-2005	Eastern North Pacific	Open water; over nearshore and shelf	Satellite telemetry
Williams and Ralston 2002	1977-1998	Southern Oregon to southern California (43°N to 34°N)	50-500 m; soft bottom	Bottom trawl
Wing et al. 1998, 2003	1992-1997	Gulf of the Farallones, California	Open water	Plankton tows, hydrography, settlement surveys
Yoklavich et al. 2000	August 1992, October 1993	Soquel Canyon, Monterey Bay, California	80-360 m; hard and soft bottom	Side-scan sonar, manned submersible, video/laser transects
Yoklavich et al. 2002	Fall 1997, Fall 1998	In and adjacent to Big Creek Ecological Reserve, central California	20-250 m; hard and soft bottom	Side-scan sonar, manned submersible, video transects
Zeidberg and Robison 2007	1989-2004	Monterey Bay, California	0-1000 m; open water	ROV, video
Zimmerman 2006	June – September; 1995, 1998, 2001	Vancouver Island, Canada to southern California	55-500 m; soft bottom	Bottom trawl

Appendix II. Catalogue of GIS Data

Figure #	Data Type	Developer (Date)	Description	Data Download
1	Hard substrate	TerraLogic GIS, Inc. (2004)	High-resolution substrate data are not available for the entire offshore environment so only low-resolution substrate data are shown. Hard substrate (especially smaller patches) is likely to be under-represented. The hard substrate data was developed by the Center for Habitat Studies, Moss Landing Marine Laboratories by synthesizing geological seafloor characteristics for the California coast, including substrate type and areas defined as submarine canyons, from various sources such as side-scan sonar and multibeam bathymetry. TerraLogic GIS, Inc then compiled this data with seafloor data from Oregon and Washington to delineate the geological seafloor characteristics of the continental margin of the West coast. These data were developed for Pacific States Marine Fisheries Commission in cooperation with the National Marine Fisheries Service Northwest Region and the Pacific Fishery Management Council in support of an Environmental Impact Statement (EIS) to consider the designation and conservation of Essential Fish Habitat (EFH) for Pacific Coast Groundfish. These data were consolidated and integrated in a GIS format to support spatially explicit groundfish habitat modeling and impacts assessment on a coastwide scale. This is a summarized data set, it has been dissolved on the Induration attribute to produce a simpler file for GIS analysis.	http://marinehabitat.psmfc.org/physical-habitat.html
1	National Marine Sanctuary boundaries	ONMS (2008)	The National Marine Sanctuary Program manages a system of sanctuaries and other managed areas around the country. These GIS compatible digital files are based on the legal definition of each sanctuary as defined in Title 15 Code of Federal Regulations, Part 922 and the subparts for each national marine sanctuary. These digital files are provided to promote an understanding of the boundaries of each national marine sanctuary; they are not intended and should not be relied upon for use in navigation or legal purposes.	http://sanctuaries.noaa.gov/library/imast_gis.html
1	Depth zones	TerraLogic GIS, Inc. (2004)	MBNMS staff developed the depth zones using the 10-meter depth zone polygons in the marine areas off California. These 10 m contour data were created by TerraLogic GIS Inc. for Pacific States Marine Fisheries Commission in cooperation with the National Marine Fisheries Service Northwest Region and the Pacific Fishery Management Council in support of an Environmental Impact Statement (EIS) to consider the designation and conservation of Essential Fish Habitat (EFH) for Pacific Coast Groundfish. These data were consolidated and integrated in a GIS format to support spatially explicit groundfish habitat modeling and impacts assessment on a coastwide scale. NOTE: The link indicates where to download the 10-m contours but a user will have to select the depth zone contour themselves to create the GIS file.	http://marinehabitat.psmfc.org/physical-habitat.html

Figure #	Data Type	Developer (Date)	Description	Data Download
1	Statewaters	NOAA (2012)	The "Statewaters" polygon represents the State Tidelands and Submerged Lands, which are defined as shoreline to 3 nautical miles offshore and includes Monterey Bay. Coastal states, such as California, were granted ownership of these lands and resources by the federal Submerged Lands Act of 1953.	http://www.marinecadastre.gov/data/default.aspx (under "Submerged Lands Act Boundary")
1	Hillshade and bathymetry of ocean	CDFG (2001)	California Department of Fish and Game staff created this grid file from 75 original tiled Digital Elevation Models (DEMs) that were mosaicked into one grid and resampled to 200 meters. The DEMs were produced by Teale Data Center. Land values are coded as zero.	http://ccma.nos.noaa.gov/ecosystems/sanctuaries/california/html/data/
2	Canyons	NCCOS (2007)	The Canyons (channels) polygon shapefile shows the location of submarine canyons and channels off the coast of California. Features were delineated using bathymetry, depth variance and 50 m contours and an existing GIS dataset developed by Greene et al. (1999). The base bathymetry layer is a mosaic of multibeam datasets collected for the California Department of Fish and Game bathymetry development project and resampled to 200 m. This bathymetry layer was chosen for its fine-scale spatial resolution and accuracy in shallow to moderate depth waters. Features greater than 5 km long and having a central channel more than 100 m below the surrounding seascape were digitized at 1:200000. Additional features were located and digitized with the help of existing GIS datasets developed by Greene et al. (1999) and NOAA NCCOS (2007). Features include both the central channel and sloping walls. In cases where two or more features where in close proximity and clearly part of the same benthic feature, they were united. Major named submarine canyons such as Monterey, Pioneer, Lucia and Sur canyons are included as well as 62 additional canyons and channels.	Not available
3	Seamounts	NCCOS (2007)	Polygons outlining physiographic areas such as canyons, seamounts and banks were developed by NOAA National Centers for Coastal Ocean Science in 2007 using bathymetric products from NOAA and MBARI. Only the polygons outlining seamounts are shown in Figure 3.	Not available
4 & 5	Oxygen minimum zone	MBNMS (2007)	The Oxygen Minimum Zone boundaries were developed using the 10-meter depth zone polygons in the marine areas off California. These 10 m contour data were developed by TerraLogic GIS, Inc. for Pacific States Marine Fisheries Commission in cooperation with the National Marine Fisheries Service Northwest Region and the Pacific Fishery Management Council in support of an Environmental Impact Statement (EIS) to consider the designation and conservation of Essential Fish Habitat (EFH) for Pacific Coast Groundfish. These data were consolidated and integrated in a GIS format to support spatially explicit groundfish habitat modeling and impacts assessment on a coastwide scale. NOTE: The link indicates where to download the 10-m contours but a user will have to select the 600 and 1000 m contour themselves.	http://marinehabitat.psmfc.org/physical-habitat.html

Figure #	Data Type	Developer (Date)	Description	Data Download
6	Chemo-synthetic Biological Communities	MBNMS/ MBARI (2012)	Locations where Chemosynthetic Biological Communities (CBC) have been observed during Monterey Bay Aquarium Research Institute (MBARI) remotely operated vehicle (ROV) surveys. Locations were obtained through a query of MBARI's public Video Annotation and Reference System (VARS) for seeps and Vesicomyidae and descendents. It is likely that CBCs occur in other portions of MBNMS, but very little exploration of deep-sea habitats has occurred outside the Monterey Bay area. In 21 years of ROV diving (1989-2010), over 16,000 hours of high-resolution video have been archived, annotated, and maintained as a centralized institutional resource. This video library contains detailed footage of the biological, chemical, geological, and physical aspects of the Monterey Canyon and other areas. MBARI developed VARS to facilitate the creation, storage, and retrieval of video annotation records from the ROV dive tapes.	http://www.mbari.org/vars/
8	Structure-forming invertebrates on hard substrate	MBNMS/ MBARI (2012)	The data layer shows the result of a MBARI VARS query in August 2012 using the following search terms: Hexactinellida and descendants (sponges), Cladorhizidae and descendants (sponges), Crinoidea, Alcyonacea, Stylasteridae, Antipatharia, and Scleractinia, all with descendants. See Figure 6 (above) for more information on VARS.	http://www.mbari.org/vars/
9	NMFS trawl corals (1980-2010)	Northwest Fisheries Science Center (2011)	Records of cold-water/deep-sea corals caught incidentally in bottom trawl surveys of groundfish conducted from 1980 to 2001 by the Alaska Fisheries Science Center (AFSC) and 2001 to 2010 by the Northwest Fisheries Science Center (NWFSC). Both science centers recorded some invertebrate catch as part of regular surveys of groundfish off the coasts of Washington, Oregon and California; however, the level of attention given to some invertebrate taxa (e.g., crabs, corals) has increased in recent years. Only records where corals were identified in the total catch are included. Each coral specimen was identified to the family level (when possible) by the biologists onboard; therefore identification was dependent on their expertise. Each tow "event" is represented by a point geo-referenced to either the vessel track midpoint position for AFSC surveys or "best position" (i.e., priority order: 1) gear track midpoint 2) vessel track midpoint, 3) vessel start point, 4) vessel end point, 5) station coordinates) for NWFSC surveys. Data were compiled by the NWFSC Fishery Resource Analysis and Monitoring Division and AFSC Resource Assessment and Conservation Engineering Division. Average lengths of tows along the seafloor for NWFSC and AFSC surveys were 1.4 and 2.6 km, respectively. It is important to note that these records represent only presence of corals in the area swept by the trawl gear. Since bottom trawl gears used during these surveys were not designed to sample emergent epifauna, absence of corals in the catch does not necessarily mean they do not occupy the area swept by the trawl gear. Trawl gear is not designed to sample the habitats in which many coral taxa reside, particularly those habitats characterized by rocky substrate and high relief. That means that the surveys	http://pacoos.coas.oregonstate.edu/

Figure #	Data Type	Developer (Date)	Description	Data Download
			tend to actively avoid untrawlable habitat. Also, until late 1990's the bottom trawl surveys extended only to approximately 550 m and the combined shelf/slope surveys since 2003 have surveyed habitat from approximately 55 m to approximately 1300 meters.	
10	Predicted habitat suitability for deep-sea corals	Guinotte and Davies (2012)	Predictive habitat models for deep-sea corals in the U.S. West Coast Exclusive Economic Zone were developed for NOAA-NMFS' Office of Habitat Conservation. Models are intended to aid in future research/mapping efforts, assess potential coral habitat suitability both within and outside existing bottom trawl closures (i.e., Essential Fish Habitat), and identify suitable habitat in National Marine Sanctuaries (NMS). Deep-sea coral habitat suitability was modeled at 500 x 500 m spatial resolution using a variety of physical, chemical and environmental variables known or thought to influence the distribution of deep-sea corals. Maxent models identified slope (1 km), temperature, salinity and depth as important predictors for most deep-sea coral taxa. Predicted habitat suitability results are not meant to identify coral areas with pin point accuracy and probably over-predict actual coral distribution due to model limitations and unincorporated variables (e.g., substrate) that are known to limit their distribution. Predicted habitat results should be used in conjunction with multibeam bathymetry, geologic maps, and other tools to guide future research efforts to areas with the highest probability of harboring deep-sea corals. Field validation of predicted habitat is needed to quantify model accuracy, particularly in areas that have not been sampled.	Not Available
12	Zones	RPI (2006)	The Environmental Sensitivity Index (ESI) data for central California were collected, mapped, and digitized to provide environmental data for oil spill planning and response. The zones differ in depth, distance from shore, and other habitat features. See the central California offshore sensitivity map for details of species present in each zone.	http://response.restoration.noaa.gov/esi
13	Pennatulacea (sea pens)	MBARI/ MBNMS (2012)	Data layer shows the result of a MBARI VARS query using the search term Pennatulacea with descendants (August 2012). See above for more information on VARS.	http://www.mbari.org/vars/
15	Demersal rockfish richness	NCCOS (2003)	This is a point file of NMFS demersal fish trawls on the continental shelf and slope that took place during the summer and fall between 1977 and 2001. Species richness values were derived from 1336 trawls conducted between 50 and 1280 meters. Species richness is defined as the number of fish species present at a given location. To calculate rockfish richness, data were tabulated to determine the number of rockfish species *Sebastes* or *Sebastolobus* present in each trawl. Trawls are only possible along relatively flat bottom areas with a minor incline and no data were available for rocky, highly sloped areas so rockfish might be under-represented in the trawl catch.	http://ccma.nos.noaa.gov/ecosystems/sanctuaries/california/html/data/

Figure #	Data Type	Developer (Date)	Description	Data Download
16	Demersal fish richness	NCCOS (2003)	This is a point file of NMFS demersal fish trawls on the continental shelf and slope that took place during the summer and fall between 1977 and 2001. Species richness values were derived from 1336 trawls conducted between 50 and 1280 meters. To calculate demersal fish richness, data were tabulated to determine the number of species present in each trawl. Trawls are only possible along relatively flat bottom areas with a minor incline and no data were available for rocky, highly sloped areas.	http://ccma.nos.noaa.gov/ecosystems/sanctuaries/california/html/data/
17	Demersal fish diversity	NCCOS (2003)	This is a point file of NMFS demersal fish trawls on the continental shelf and slope that took place during the summer and fall between 1977 and 2001. Diversity estimates were derived from 1336 trawls conducted between 50 and 1280 meters. Diversity reflects the distribution of species abundance within a trawl and was calculated using the Shannon index (H'). Trawls are only possible along relatively flat bottom areas with a minor incline and no data were available for rocky, highly sloped areas.	http://ccma.nos.noaa.gov/ecosystems/sanctuaries/california/html/data/
20	Leatherback sea turtle critical habitat	NMFS (2012)	This data layer is intended to represent the areas designated as critical habitat for the endangered leatherback sea turtle. This data set is meant as a general locational reference for these designated areas. Please refer to the Federal Register Notice titled " Endangered and Threatened Species: Final Rule to Revise the Critical Habitat Designation for the Endangered Leatherback Sea Turtle " (77 Federal Register 4170, January 26, 2012) for details and the legal definition.	http://www.nmfs.noaa.gov/gis/data/critical.htm#nw
20	Leatherback sea turtle hotspots and principal foraging area	MBNMS (2012)	These GIS data layers were developed by the Monterey Bay National Marine Sanctuary staff under the direction of Scott Benson (NMFS Southwest Fisheries Science Center) to portray hotspots and principal foraging area of the leatherback sea turtles. Hotspots are areas within the principal foraging area where leatherback sea turtles have been encountered most frequently. The principal foraging area extends offshore to the 200 m isobaths and is part of Area 1 identified in 77 Federal Register 4170, January 26, 2012. The preferred prey of leatherback sea turtles, brown sea nettles (*Chrysaora. fuscescens*), are found in abundance and high densities in this area particularly within upwelling shadows and retention areas.	Not Available
21	Offshore hotspots for seabirds	RPI (2006)	Eight zones were created by the USGS, NOAA and MLML seabird experts in order to depict the overall distribution of pelagic species on the Central California Offshore Sensitivity Map. These polygons were developed to provide a regional overview of the environmentally sensitive offshore resources of the Central CA coast and the MBNMS as part of the Environmental Sensitivity Index (ESI) which characterizes marine and coastal environments and wildlife by their sensitivity to spilled oil.	http://response.restoration.noaa.gov/esi

Figure #	Data Type	Developer (Date)	Description	Data Download
22	Offshore hotspots for marine mammals	RPI (2006)	Eight zones were created by the USGS, NOAA and MLML marine mammal experts in order to depict the overall distribution of pelagic species on the Central California Offshore Sensitivity Map. These polygons were developed to provide a regional overview of the environmentally sensitive offshore resources of the Central CA coast and the MBNMS as part of the Environmental Sensitivity Index (ESI) which characterizes marine and coastal environments and wildlife by their sensitivity to spilled oil.	http://response.restoration.noaa.gov/esi
23	Upwelling zones	TNC (2006)	To identify recurring patterns of cold water as indicators of upwelling zones, The Nature Conservancy (TNC) utilized 1999-2002 AVHRR (Advanced Very High Resolution Radiometer, 1.1 km resolution) data compiled by NOAA Coast Watch (west coast node) to derive average sea surface temperatures during the upwelling season (March - September). For this analysis TNC used the High Resolution Monthly Composites product from NOAA which compiles AVHRR data by month for scene footprints that are approximately 300,000 km^2. The composites were created using night time images only, computing median values. A monthly composite for each month (March - September) and each year 99-02 was downloaded making for a total of 96 files (6mo * 4years * 4 scenes).	Not Available
24	Frontal probability index > 20% per quarter	Coastwatch (2007)	The CoastWatch Oceanic Front Probability Index measures the probability of sea surface temperature (SST) front formation based on data from NOAA's GOES satellites. Daily average SST is generated from the GOES data. Fronts are identified by applying an edge detection algorithm to this daily averaged SST field (Breaker et al. 2005). Pixels with gradients greater than 0.375 °C are classified as a front. The frontal probability index (FPI) is then calculated as the number of times a pixel is classified as a front divided by the number of cloud free days per month. Pixels with a monthly FPI of 20% or greater are selected and averaged for all months within a given season (Jan-March, April-June, July-Sept., Oct-Dec.) for the entire duration of the data set (2001-2006). Nearshore areas are not surveyed by the GOES data.	Not Available

Figure #	Data Type	Developer (Date)	Description	Data Download
25	Predicted hotspots of multispecies seabird aggregations	PRBO (2012)	Data from at-sea surveys of seabirds over an 11-year period (1997-2008) were combined with information on habitat features (bathymetry and oceanography) to predict hotspots for seabirds (Nur et al. 2011). Single species model predictions for 16 species were combined to identify potential multispecies hotspots using three criteria: abundance, importance, and persistence. The spatial scale of the models was 38.5ºN to 35ºN from the shoreline to 600 km offshore. Seabird species: Black-footed Albatross (*Phoebastria nigripes*), Bonaparte's Gull (*Larus philadelphia*), Brandt's Cormorant (*Phalacrocorax penicillatus*), Brown Pelican (*Pelecanus occidentalis*), Cassin's Auklet (*Ptychoramphus* aleuticus), California Gull (*Larus californicus*), Common Murre (*Uria aalge*), Fork-tailed Storm-Petrel (*Oceanodroma furcata*), Glaucous-winged Gull (*Larus glaucescens*), Heermann's Gull (*Larus heermanni*), Herring Gull (*Larus argentines*), Leach's Storm-Petrel (*Oceanodroma homochro*), Red-necked Phalarope (*Phalaropus lobatus*), Sabine's Gull (*Xema sabini*), Sooty Shearwater (*Puffinus griseus*), and Western Gull (*Larus occidentalis*). The "Abundance" values represent the summed, standardized abundance for all 16 seabird species as number of birds per square kilometer. To calculate 'importance' for each of the 16 species, PRBO staff ranked all prediction cells according to the predicted abundance of that species by month and year. Then they identified the smallest set of cells that together constituted 25% of the species' total predicted abundance within the study region. These "highest predicted density" cells were considered to indicate a species' "core area" and were assigned a score of 2. The set of cells that together made up the next quartile of the species' total abundance based on predicted density, were considered important "shoulder" areas and were assigned a score of 1 The remaining 50% of cells received a score of 0. Importance was calculated for each species and a weighted average was then calculated over all species. The weighting function was scaled to have mean = 1. The product of the weighting factor and the number of core cells for each species was the same across all species. Importance was calculated separately by month and year, and then results were averaged over all years and months. 'Persistence' was first calculated for individual species for each month separately (February, May, July, October). The number of years (out of 11) that a cell was in the top 5 percent of predicted abundance for that species was scored (i.e., in the 95th percentile of all prediction cells for that month). The persistence score for a cell was then averaged over species and months.	Not Available

Figure #	Data Type	Developer (Date)	Description	Data Download
26	Cetacean modeled species densities	Barlow et al. (2009), Forney et al. (2012,) Becker et al. (in review).	NMFS staff used data from 16 shipboard cetacean and ecosystem assessment surveys to develop habitat models to predict density for 12 cetacean species in the California Current Ecosystem (CCE). The CCE study area included the offshore area South of 48ºN (Puget Sound in WA) and North of 30ºN (US-Mexico border) and out to 131ºW (about 300 nautical miles offshore) (Hamilton et al. 2009). All data were collected by NOAA's Southwest Fisheries Science Center (SWFSC) from 1986-2008 using accepted, peer-reviewed survey methods. The expected number of groups seen per transect segment and the expected size of groups were modeled separately as functions of habitat variables. To evaluate predictive power, Generalized Additive Models (GAMs) with nonparametric smoothing functions were used to build the best-and-final models using 5 km transect segments. Oceanographic habitat data from in situ measurements and remotely sensed measurements from satellites were integrated in the final models. Only sea surface temperature (SST) and measures of its variance were available from remotely sensed sources, whereas the in situ measurements also included sea surface salinity, surface chlorophyll and vertical properties of the water-column. In some years, in situ data also included net tows and acoustic backscatter. Model predictions were then used in standard line-transect formulae to estimate density for each transect segment for each survey year. Predicted densities for each year were smoothed with geospatial methods to obtain a continuous grid (25 by 25 km grids) of density estimates for the CCE. These annual grids were then averaged to obtain a composite grid that represents the best estimates of cetacean density (animals per km^2) over the years in the CCE.	http://cetsound.noaa.gov/cda.html
27	Stratified estimated harbor porpoise density	SWFSC (2009)	Stratified estimates of harbor porpoise density were compiled from species-specific aerial surveys from 2002-2007. Two sets of transects, one inshore (out to the 90 m isobath) and another offshore (out to roughly the 200 m isobath) were surveyed to ensure that all harbor porpoise habitat was included in the surveys.	http://cetsound.noaa.gov/cda.html

Appendix III. Benthic-Pelagic Coupling

Benthic-pelagic coupling - the two-way exchange, or flux, of matter between the benthos and the overlying water column - is important for both benthic and pelagic compartments. This flux occurs through the sinking of non-living organic matter and the active movement of organisms both upward into the water column and downward to the seafloor. Sinking, non-living organic matter comes in numerous forms (reviewed by Smith and Demopoulos 2003) including: 1) very small organic particles (e.g., particulate organic carbon and particulate total nitrogen); 2) small aggregates of detritus that consist of dead plankton, discarded feeding structures, fecal pellets, and other organic debris – also called marine snow; 3) detritus from marine plants and algae – also called macrophyte detritus); and 4) carcasses of large animals (e.g., fishes, seabirds, marine mammals).

Most of the small particles and aggregates of marine snow that reach the deep seafloor are less than 5 mm in size and sink slowly - their descent may last for months (Robison et al. 2005). The quality and quantity of sinking food material varies both temporally and spatially. Pulses of small particle flux are coupled to periods of high surface productivity (Pilskaln et al. 1996, Smith and Demopoulos 2003). Areas of high surface productivity (e.g., upwelling zones) and areas where surface and mid-water planktonic species are concentrated (e.g., retention zones, frontal zones) tend to have higher rates of flux of organic matter to the seafloor. Shelf and slope sediments beneath upwelling zones typically are more enriched with organic matter and the availability of organic matter appears to play a dominant role in controlling regional variations in biotic structure of benthic faunal communities (Smith and Demopoulos 2003).

In addition to small sinking particles, organic matter is delivered passively to the benthos in larger parcels ranging in size from drifting algal mats to fish carcasses to whale carcasses. These depositional events deliver large quantities of organic matter to the seafloor and support associated benthic communities for a few weeks, in the case of macroalgal detritus, up to many years, in the case of a whale fall (Smith and Demopoulos 2003). In general, deposition of large particles is not predictable over space or time. However, macroalgal detritus tends to accumulate in certain areas, such as the heads of submarine canyons down current from kelp beds.

Flux of organic matter between benthic and pelagic compartments also occurs through the active movement of organisms. The deep scattering layer is composed of a loose assemblage of pelagic species that moves up to surface waters at night and down to the mesopelagic layer during the day in a process called diel vertical migration. Animals that undertake diel vertical migration (e.g., krill, jellyfish, sergestid shrimp, and lanternfishes) feed at the surface and carry the food in their guts down to midwater depths. This process greatly increases the export of carbon from the surface to the meso- and bathypelagic waters (reviewed in Raeffiella et al. 2003). In addition, fecal pellets that are voided at depth during the day greatly increase the flux of carbon from the surface to the seafloor. It has been estimated that, in the Pacific, some 43% of the individuals and 47% of the biomass migrate from below 400 m by day to above this depth at night (Maynard et al. 1975, cited in Raeffiella et al. 2003).

Upward flux occurs when pelagic organisms feed on demersal organisms. For example, northern elephant seals and sperm whales dive hundreds of meters to feed on demersal fishes. Jellyfish have been observed "feeding" on the bottom and then re-entering the water column and a large isopod was observed grabbing a larvacean house off the bottom and taking it up into the water column presumably to feed on it (Bruce Robison, pers. comm.). In addition, many benthic organisms, such as infaunal and epifaunal invertebrates and demersal fishes, release buoyant eggs or larvae into the water column (see Wakefield and Smith 1990 for an example). Pelagic larval fishes and invertebrates spend weeks to months (depending on the species) in the water column, often consuming small phytoplankton and zooplankton and being consumed by larger pelagic organisms. The settlement of the surviving larvae as benthic juveniles is another significant source of downward flux of organic matter.

Appendix IV. Definition of Terms

Assemblage: a general term for species that co-occur in a particular area without regard to their ecological interactions or their relative abundance.

Bathypelagic Zone: aphotic layer of the open sea, from 1,000 meters to at least 4,000 meters deep.

Benthic: relating to the seafloor

Benthic-Pelagic Coupling: the two-way exchange, or flux of matter, between the benthos and the overlying water body. This flux occurs through sinking of non-living organic matter (e.g. plankton tests, fecal pellets, animal carcasses, drift algae) and the active movement of organisms.

Benthopelagic: organisms swimming or drifting in the waters immediately over the seafloor

Biogenic Habitat: the physical structure of the habitat is created by living organisms.

Biological diversity (biodiversity): a measure of the variability among living organisms from all sources including diversity within species, between species and of ecosystems.

Biomass: The total quantity or weight of organisms in an area.

Chemosynthesis: the process by which organisms use energy from chemicals, such as hydrogen sulfide, to convert water and carbon dioxide into organic carbon (carbohydrates). Chemosynthetic organisms found in the ocean are bacteria, but many of these bacteria live inside larger organisms (such as clams or tube worms).

Consumers: an organism that feeds on other living organisms.

Demersal: close to or lying on the bottom, but not attached or buried.

Deposit feeder: animal that feeds on organic matter that settles on the bottom.

Detritivores: animals that feed primarily on detritus.

Detritus: decaying organic matter found in bottom sediments.

Epifauna: animals that live on the surface of the seafloor.

Epipelagic Zone: photic layer of the open ocean usually from the surface to about 200 meters deep.

Facilitation: a type of species interaction that benefits at least one of the participants and causes harm to neither. Mutualism and commensalism are types of facilitation.

Federal Waters: ocean waters between 3 and 200 nautical miles offshore, which comprises the Exclusive Economic Zone (EEZ).

Fauna: the animals of particular habitat or area.

Feeding Ground: An area used by a species for feeding.

Filter feeder: animals that feed by straining suspended matter and food particles from water, typically by passing the water over a specialized filtering structure (a sub-group of suspension feeders).

Ichthyoplankton: includes fish eggs, newly hatched eggs, young fish, and adults of small fish that are not strong swimmers.

Infauna: animals that live burrowed in the sediments.

Macrofauna and meiofauna: animals that live on or in the sediments and are not readily visible to the naked eye. Meiofauna are smaller than macrofauna, but the size limit that distinguishes the groups is not agreed upon universally.

Macrophyte: plant or alga that is easily seen without aid of a microscope.

Marine Snow: aggregations of detritus, visible to the naked eye, that consist of dead organisms, discarded feeding structures, fecal pellets, and other organic debris. In the deep ocean, marine snow is a continuous shower of mostly organic detritus that originates in the productive photic zone.

Megafauna: animals readily visible to the naked eye. This group is comprised mainly of the echinoderms (e.g. sea stars, sea cucumbers), arthropods (e.g. crabs, shrimp), bottom fishes, cnidarians (e.g. anemones, sea pens) and larger polychaetes (segmented worms).

Mesopelagic Zone: disphotic zone from 200 to 1,000 meters deep, where little light penetrates and the temperature gradient is even and gradual with little seasonal variation. This zone contains an oxygen minimum layer and usually has the maximum concentrations of the nutrients nitrate and phosphate. It overlies the bathypelagic zone and is overlain by the epipelagic zone.

Migratory Corridor: a path used by a species to move from one area to another (e.g., between spawning or breeding grounds and feeding grounds).

Nekton: ocean organisms that are active swimmers, such as fishes, squid, and marine mammals.

Nursery Habitat: a habitat in which the juvenile phase of one or more species congregates. Habitats used as nurseries may provide advantages to juveniles, such as increased growth rates or lower predation rates, compared to non-nursery habitats.

Overfished: stock size below 25% of unfished biomass.

Oxygen Limited Zone (OLZ): the region immediately above or below an OMZ with an oxygen concentration of <60 μmol/kg

Oxygen Minimum Zone (OMZ): zone in which oxygen saturation in seawater is at its lowest (<0.5 ml/L or <20 μmol/kg). This zone occurs at depths of about 600 to 1,000 meters, depending on local circumstances.

Pelagic: inhabiting the open ocean, especially near the surface.

Photosynthesis: process of using the energy in sunlight to convert water and carbon dioxide into organic carbon (carbohydrates). Photosynthetic organisms found in the ocean are phytoplankton, algae, and marine plants.

Phytoplankton: the photosynthetic component of the plankton consisting primarily of single-celled algae and bacteria.

Planktivores: animals that feed primarily on plankton.

Plankton: plants and animals that float or drift in the water.

Primary Production: conversion of inorganic carbon (e.g, carbon dioxide, methane) into organic carbon (food). Photosynthesis and chemosynthesis are two processes used by organisms to complete this conversion.

Productivity Hotspot: A place of higher than usual productivity.

***Sebastomus* Group:** natural assemblage of rockfishes (and valid subgenus of the genus *Sebastes*) sharing various morphometric characteristics, most notably 4-5 white dorsal blotches. Species in this group include, greenblotched, greenspotted, pink, pinkrose, rosethorn, rosy, starry, and swordspine rockfishes.

Spawning/Breeding Ground: An area used by a species for reproduction.

Species Composition: The assemblage of species that are characteristic of an area.

Species Diversity: there are several measure of diversity, the simplest index is species richness (the number of species in a system); other indices include a measure of abundance, such as evenness (the relative abundance of each species in a system). These measures do not detect species substitutions or replacements and, thus may not capture substantial changes in biological systems.

State Waters: ocean waters between the coastline and 3 nautical miles offshore. There are, however, exceptions to the distance offshore, as in Monterey Bay.

Suspension Feeder: an animals that feeds by straining suspended matter and food particles from water.

Topography: the surface features of an area

Trophic: the feeding habits or food relationship of different organisms in a food chain

Upwelling: process by which water rises from a deeper to a shallower depth, usually as a result of offshore surface water flow. It is most prominent where persistent wind blows parallel to a coastline so that the resultant Ekman transport moves surface water away from the coast.

Zooplankton: animal component of the plankton consisting of both microscopic and much larger organisms.

Appendix V. List of Acronyms

AFSC: Alaskan Fisheries Science Center

ASFA: Aquatic Sciences and Fisheries Abstracts

CBCs: Chemosynthetic Biological Communities

CDFG: California Department of Fish and Game

CESA: California Endangered Species Act

DA: Domoic Acid

DSMZ: Davidson Seamount Management Zone

EFH: Essential Fish Habitat

EIS: Environmental Impact Statement

ESA: federal Endangered Species Act

GIS: Geographical Information Systems

HAB: Harmful Algal Bloom

IfAME: Institute for Applied Marine Ecology

IUCN: World Conservation Union

MARS: Monterey Accelerated Research System

MBARI: Monterey Bay Aquarium Research Institute

MBNMS: Monterey Bay National Marine Sanctuary

MLML: Moss Landing Marine Laboratories

MLPA: Marine Life Protection Act (in the state of California)

MPA: Marine Protected Area

NCCOS: National Centers for Coastal Ocean Science

NMFS: National Marine Fisheries Service

NOAA: National Oceanic and Atmospheric Administration

NWFSC: Northwest Fisheries Science Center (part of NMFS)

OLZ: Oxygen Limited Zone

OMZ: Oxygen Minimum Zone

PDO: Pacific Decadal Oscillation

PFMC: Pacific Fisheries Management Council

POC: Particulate Organic Carbon

POM: Particulate Organic Matter

PTN: Particulate Total Nitrogen

ROV: Remotely Operated Vehicle

SWFSC: Southwest Fisheries Science Center (part of NMFS)

UCSC: University of California, Santa Cruz

USGS: United States Geological Survey

VARS: Video Annotation and Reference System

VOM: Vertical Ontogenetic Migration

YOY: Young-of-the-Year

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